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INDIA'S MINERAL WEALTH

आकरप्रभवः कोशः

'Mines are the sources of the treasury.'

—Kautilya, 321-296 B.C.



INDIA'S MINERAL WEALTH

*A Guide to the Occurrences and Economics
of the Useful Minerals of
India, Pakistan and Burma*

6472

BY

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INTRODUCTION

ALTHOUGH there is abundant evidence of the skill and industry of the ancient miners of India in winning gold, extracting and smelting the ores of the commoner metals and in recovering diamonds from deposits of various kinds, but little systematic mining, as the term is understood today, had been attempted in India, Pakistan or Burma before the last decades of the nineteenth century. The author of the pioneer work on Indian economic geology, published in 1881, states that mining for metallic ores by public companies had not been successful up to that time, though coal and salt mining and the quarrying of building materials had been carried on both by the Government and by private concerns, with in many cases very great profit. 'It would seem, however,' he added, 'that as regards the metals there is a new era about to commence, and that the capabilities of India, not only as a gold-producing country, but also in reference to other metals, will in the course of the next few years be for the first time fairly tested.'

Valentine Ball read the signs of his time correctly, for later developments in the course of the next few years fully justified the truth of his prediction. Mineral deposits of many kinds were discovered and explored; the platitude that they were as a whole too lean to support large-scale treatment died a natural death, and although exploitation for a time resulted mainly in the export of raw products to foreign countries, the advantages to be gained by dealing with them on the spot came to be realized, and India began to advance to her proper position amongst the mineral-producing and metallurgical nations of the world.

By 1899 the growth of prospecting necessitated the issue by the Government in that year of rules to govern the grant of prospecting licences and mining leases, and the number of concessions taken up by private individuals and companies, over lands in which the mineral rights had been retained by the State, rapidly increased from an average of 370 per annum for the first decade of the present century to 706, the corresponding figure for the ten years ending 1930. Over the eight years ending 1938 the average had fallen to 555, of which nearly half had been granted in Burma. The separation of Burma from India took place on 1 April 1937, and it became an independent Union of States in 1948, but the Japanese invasion in 1942 completely shattered its prosperous mining and metallurgical industries, and internal unrest has hitherto prevented their restoration to any semblance of their former importance.

To register the progress of the mineral industry over the whole vast region now occupied by India, Pakistan and Burma, a *Review of the Mineral Production of India* was issued annually by the Reporter on Economic Products to the Government of India for the four years 1894-7, but in 1898 it was decided to publish reviews of progress at wider intervals, covering periods long enough to permit of the determination of any secular variations. The first of these reviews, dealing with the six years 1898-1903, appeared in the *Records of the Geological Survey of India* in 1905, and since then quinquennial reviews of the same character have been forthcoming. In addition to these, a brief annual statement of the quantity and value of all the minerals raised, for which returns are available, has appeared in each annual volume of the *Records* since 1906, accompanied of later years by trade statistics which enable the consumption of any particular product within the country to be gauged. By the end of 1946 no less than 2,090 mineral concessions had been granted in the area which now constitutes the Indian Union, of which 213 were prospecting licences, 1,165 mining leases and 712 quarry leases; moreover, these figures refer only to Government-owned lands and do not include any concessions granted over *zamindari* lands or in the Indian States. This great increase was partly due to the stimulus of war and partly to the urge to render the country free of imported supplies, but it has its dangers when concessionaires are speculators more anxious to sell out at a profit than fulfil their obligations to prospect and develop the properties granted to them.

A great and growing literature exists on both the scientific and economic aspects of the mineral deposits of India, Pakistan and Burma. Apart from the papers scattered through the eighty-three annual volumes of the *Records of the Geological Survey of India* available to date, or the monographs devoted to such separate subjects as coal, oil, manganese, mica, etc., or again, those dealing with the mineral resources of separate States, such as Madras, Orissa, Madhya Pradesh, etc., to be found amongst the eighty volumes of the *Memoirs* of the same Department, a mass of information regarding them is to be found in the forty-six volumes of the *Transactions of the Mining, Geological and Metallurgical Institute of India*, in those of the *Geological, Mining and Metallurgical Society of India* and in many other publications too numerous to be detailed here. A synopsis of the literature available up to 1916 is to be found in Part II of the *Bibliography of Indian Geology and Physical Geography*, by T. H. D. La Touche, and this has been kept up to date by the publication of lists of later papers as appendices to the *Annual Reports of the Geological Survey of India*.

But few readers, apart from professional specialists, have either the time or the opportunity to search for information in a multitude of official reports or the transactions of learned societies, which in any case are only obtainable in the larger libraries. For this and

other reasons, summaries of all the salient facts are needed from time to time in which the growth of the mineral industry itself can be recorded; the progress of those others dependent on it for their basic materials reviewed; its impact on the economic life of the country generally examined, and any likely means of increasing its extent for the benefit of the community at large indicated.

In 1908 Sir Thomas Holland published a *Sketch of the Mineral Resources of India*, and in 1923 one of the present authors (Coggin Brown) was instructed by the Director of the Geological Survey of India at that time, the late Sir Edwin Pascoe, to prepare an account on the same lines in as condensed and popular a form as possible. This was published by the Oxford University Press, in its *India of To-Day* series, under the title *India's Mineral Wealth*, but whereas Sir Thomas Holland dealt with 54 distinct mineral products, it was then found necessary to consider 77. In a greatly enlarged second edition of this work written with the approval of the Government of India and again published by the Oxford University Press in 1936, the total had increased to 110.

About 1908 the total annual value of minerals raised in India as it then was amounted to an annual average of about Rs 10½ crores (£7 million); about 1928, the corresponding figure was almost Rs 32 crores (£24 million) and by 1938, the last complete year before the outbreak of the second world war, it had risen again to some Rs 44 crores (about £33 million), to which Burma contributed approximately Rs 10 crores. Over the three decades thus covered remarkable progress had been achieved; several new coalfields had been developed; fresh oilfields drilled and the unknown depths of existing ones explored; the enormous iron ore fields of Bihar and Orissa had been proved and a great iron and steel industry with its attendant satellites had been established. Metallurgical centres had arisen at Maubhandar in Bihar, where the copper ores of Singhbhum were smelted and refined copper and yellow metal products manufactured, and at Nam Tu, in the Shan States, where the ores from Bawdwin were made to yield their contents of lead, silver, copper, antimony and nickel, and zinc concentrates were also prepared. The wolfram deposits of Lower Burma had proved to be of wide extent and richness, while the associated tin ore was being recovered both by mining and dredging methods. The beach sands of Travancore, the largest and richest in monazite in the world, were also being treated for their content of ilmenite and zircon. The gold mines at Kolar were becoming the deepest in the world, and India continued to head the list of the world's mica producers, while her manganese ore deposits gave her the same position from time to time. With the growth of the iron and steel industry the demand for refractory materials had resulted in the creation of works specializing in the production of such goods, while Indian cement works satisfied most of the country's needs. In other directions, however,

progress had been disappointingly slow, and vast quantities of materials, made in other lands from mineral products obtainable in India, continued to be imported.

Such were the general outlines of the position when the world was convulsed by the outbreak of war in 1939. The momentous changes which followed it, the freedom of India from British control, the division of the subcontinent between India and Pakistan in 1947, the foundation of an independent Burma in 1948 and the birth of the Republic of India on 26 January 1950—great dynastic events of such magnitude could not fail to have profound effects on the mineral industries of the countries concerned. Yet the total value of the minerals and ores produced in the Republic alone continued to increase and had reached a total of over Rs 83½ crores in 1950 and Rs 105 crores in 1951. In the case of Pakistan, incomplete figures register an increase from over Rs 1½ crores in 1948 to more than Rs 2½ crores in 1950.

Most of the successful mineral industries in India, Pakistan and Burma today owe their origin to the pioneering explorations of the Geological Survey of India which celebrated its centenary in 1951; yet, before the war in 1939, its scientific staff numbered but 27 officers, called upon to work anywhere from the confines of China to those of Iran (and occasionally to cross them), or from Travancore to the frontiers of Tibet and Afghanistan. The attitude of the New India towards the development of its mineral heritage is revealed in the increase in the cadre of the Survey to 150 officers and a total staff of 550, by 1948, as part of a reorganization not yet completed. The whole territory of the Republic is now covered by five independent circles each with its own Survey Party. In addition to these, two separate bodies of specialists deal with the problems of Mineral Development and of Engineering Geology and Ground Water, the former including geophysicists, etc. The headquarters of the whole Department, now under the control of Dr M. S. Krishnan, are in Calcutta and here also are the usual laboratories and workshops, drawing office, library and museum, as well as the Mineral Information Bureau which provides free advice on the uses and processing of raw materials and on their availability for any particular purpose. The publication of its Journal, *Indian Minerals*, now in its sixth volume, commenced in 1947, its main object being the dissemination in non-technical language of facts and correct information relating to its title.

In the Five-Year Plan of the Government of India the bearing of the mineral industry on the future industrial progress of the country is stressed; furthermore, a definite mineral policy has been adopted in which both the further investigation of resources and the proper appraisal of the known reserves have priority. The Mines and Minerals Regulation and Development Act became law in 1948, and the obsolete Rules regarding the grant of Mineral Concessions were replaced by new ones more in keeping with the

times in 1949. A Bureau of Mines was created in order to secure co-ordinated working of leased and prospecting areas under efficient technical control, and to ensure that due regard is paid to the prevention of waste and to proper principles of conservation. The importance attached to research is sufficiently indicated by the formation of the Fuel Research Institute at Digwadih, near Dhanbad, the National Metallurgical Laboratory at Jamshedpur, the Central Glass and Ceramics Research Institute at Calcutta, the Central Electro-Chemical Research Institute at Karaikudi, in addition to the National Chemical and Physical Laboratories, at Poona and Delhi respectively.

In its Statement of Industrial Policy of 2 April 1948, the Government of Pakistan indicated that the mineral industry would be subjected to central planning, a decision which was implemented by the Regulation of Mines and Oilfields and Provincial Development (Federal Control) Act, 1948. A Department of Mineral Concessions was instituted in June 1949 to administer the Act, and appropriate Rules governing the grant of prospecting licenses and mining leases have been promulgated. The nucleus of the Geological Survey of Pakistan was formed in Quetta, in 1947, by a superintending geologist, six assistant geologists and a few clerks and technicians from the Geological Survey of India; today it contains 25 gazetted officers in a department subordinate to the Ministry of Industries. Several valuable reports of its operations have already been published as *Records* of the Geological Survey of Pakistan.

In the Two-Year Plan of Economic Development of Burma issued in April 1948, great emphasis was laid on the development of mineral resources. It was considered that 'a scientific and accurate assessment of the mineral resources of Burma is essential to the evolution of a comprehensive, fully co-ordinated policy of economic development. The means for such an assessment were sadly lacking in the past and this deficiency must be remedied as early as possible'. The Government has planned to expand both the Geological and Mining Departments. In the Geological Department there are at present one Senior Geologist and two Junior Geologists. The recruitment of a Deputy Director who will later fill the post of the Director and of two Field Geologists has already been sanctioned. In the Mining Department there is now one Mining Adviser and a Junior Mining Adviser. In the meantime the Government engaged, on 27 August 1951, an American consulting firm for two years to make a thorough survey of the mineral resources of the country. According to its policy of 'joint ventures' with foreign interests, stated early in 1951, the Burma Corporation has become a joint enterprise with governmental participation. Later, in 1952, a Mineral Development Corporation of Burma was founded to plan the development of all the mineral resources of the country.

Indian mineral statistics were for long grouped into two classes, those for which approximately trustworthy returns were available, and those for which regular and complete returns were not forthcoming. This system, which commenced in 1894, continued until 1938, but with the efflux of time and the growth of more effective measures for collecting production figures, the number of minerals included in the first class gradually increased at the expense of those in the second one. In 1938, therefore, the dual system was abandoned, though it must be admitted that for minerals still won by primitive methods, though they may form the bases of extensive industries, carried on by a large number of persons working on a small scale independently, in a large number of places, the accuracy of the returns still leaves much to be desired. Accurate statistics and their timely publication are essential for the information of industrialists and others concerned with the mineral trade, as well as for Government itself in framing administrative policy and planning further development. With the consolidation of the pre-Independence Provinces and the Princely States into the Indian Union, and the extension of the Indian Mines Act to all its territories except Jammu and Kashmir, it has become possible to adopt a uniform system of collection and collation of information, and in the near future it will be possible to obtain a much clearer picture of the economics of Indian mining and the mineral industries than at any time during the past fifty or sixty years.

Another innovation also appeared in 1938, when a system previously adopted only in the case of the Shan States was adopted for the whole of India. Under this system the values of the raw ores and minerals are inflated by the addition of the values of the metallic products made from some of the ores; for example, the total value of the mineral production in 1937 using the older method of computation was Rs 21,20,31,432 (£15,942,213), but under the newer one it becomes Rs 30,49,43,161 (£22,928,058), a rise of no less than 43.8 per cent. Such a system is of very doubtful validity and if adopted should logically be extended to every ore and mineral in the list, but as this is manifestly impossible, in order to avoid misinterpretation and confusion, it is advisable to maintain two lists, one for ores and raw minerals and the other for metals smelted or products made from them, in cases where accurate figures of their production are obtainable. This is the method which happily has been followed in more recent annual reports of Indian mineral production. Another cogent reason for the collection of accurate mineral statistics lies in the fact that without them the correct assessment of royalty is not possible. The rate of royalty generally assessable on the various minerals produced in India today is five per cent of their sale value at the pit's mouth, though in the case of the ores of iron, lead, zinc and copper, the rate is somewhat higher. Taking the minimum rate of 5 per cent, the total revenue from this source payable to the various State

Governments and Zamindaris increased from approximately Rs 3½ crores in 1949 to Rs 4 crores in 1950 and Rs 5½ crores in 1951, the royalty on petroleum being omitted in the two latter years.

In the table on pp. xx-xxi, the average annual values of a series of minerals and their products belonging to the first class are tabulated over a series of eleven periods, ranging from 1898 to 1951 and thus representing roughly half a century of progress. The only ones which, appearing early in the list, have disappeared entirely from it, are the antimonial lead, nickel speiss, tin ore, amber, jadeite and rubies from Burma, though the marked reduction of values for silver, lead, wolfram, zinc concentrates and petroleum, after the period 1934 to 1938, is due to the same cause, for at the time of the separation of the two countries Burma was responsible for about 23 per cent of the total value. The separation of Pakistan did not have the same effect, for in 1946, the last complete year before that change took place, the Indian Union alone produced approximately 97 per cent of the combined total value of the mineral production of both countries, the chief items on the debit side as far as India was concerned, after separation, being petroleum, salt and other natural compounds of sodium, chromite and gypsum. Such mineral statistics as are available for Burma and Pakistan since they became independent lands, are not included in the table but are to be found in later pages under the titles of the particular minerals concerned.

Collections of statistics of this kind are of internal, comparative value only, as indications of general trade trends. When compared with the absolute values of the mineral products of other countries, they are liable to be misleading without further explanation. As examples: the value of the coal raised over by far the greater part of the whole period, represents an approximate pit's mouth figure, which bore little resemblance to its selling price in the Indian market. The value of the petroleum too was for many years greatly underestimated. The figures given for salt are exclusive of its duty, the principal value of the commodity to the Government of the day, and over a long period equal to seven times the 'production' value. The export values attributed to mica were not connected in any apparent way with the declared production values at the mines. The figures for jadeite are not complete, and those for rubies and associated gems represent the output of a single European company, as no attempt was ever made to tabulate the results of a flourishing indigenous industry. Further instances might be added, but these will suffice to demonstrate the necessity of a separate analysis in each case before any attempt is made to visualize future tendencies.

Developments of major importance in the last few years include the connexion of unworked coalfields with the railway system, the introduction of measures for the conservation of coking coals, the discovery of an extensive lignite field in Madras, of

AVERAGE ANNUAL VALUES OF CERTAIN INDIAN MINERALS AND THEIR PRODUCTS (In thousands of Rupees).
METALS AND ORES

	1898-1903	1904-8	1909-13	1914-18	1919-23	1924-8	1929-33	1934-8	1939-43	1944-8	1949-51
Antimonial Lead & Antimony Ore	..	..	..	..	..	277	244	331	207½	1,248½	6,87
Chromite	..	1,36	64	3,02	6,72	6,36	5,05	5,83	7,73	7,56	6,87
Copper Ore & Matte	..	..	..	1,86	3,62	39,56	59,18	59,84	59,91	70,16	1,41,60
Gold	2,85,71	3,39,94	3,36,28	3,38,80	2,71,92	2,25,01	2,26,29	3,62,67	3,73,11	4,15,26	5,88,80
Ilmenite	..	..	..	..	..	2,27	5,99	9,61	8,83	20,22	40,18
Iron Ore	2,04	2,06	4,43	5,22	15,54	47,38	43,89	39,71	55,19	72,88	1,63,26
Lead & Lead Ore	..	..	19,32	53,85	1,18,35	2,22,16	1,55,46	1,62,40	1,64,82½	2,29	10,96
Manganese Ore*	11,92	94,76	1,23,43	1,57,86	2,57,93	2,72,58	97,20	1,29,17	1,95,18	1,41,85	10,21,68
Nickel Spels	..	..	..	..	..	1,42	8,10	13,05	12,61½	..	.. 64
Silver	..	..	1,40	20,40	84,97	1,01,99	73,16	77,86	448	50	.. 52
Tin & Tin Ore	1,03	1,65	4,52	11,01	27,43***	47,44	47,71	99,11	..	.. 47"	.. 52
Wolfram	..	..	11,47	69,25	15,81	4,87	13,58	56,05	1,24	..	2,25
Zinc Concentrates*	..	..	..	..	3,67	50,55½	28,74	38,06	21,51	..	..

FUELS

	1898-1903	1904-8	1909-13	1914-18	1919-23	1924-8	1929-33	1934-8	1939-43	1944-8	1949-51
Coal	1,83,85	3,20,99	4,45,40	6,62,88	12,33,32	11,21,84	7,87,90	7,50,61	12,23,96	36,81,21"	48,24,11
Petroleum	27,87	88,93	1,39,21	1,61,04	9,24,11	8,45,95	5,78,73	6,48,92	1,85,438½	1,30,71½	..

GEMS AND SEMI-PRECIOUS STONES

	1898-1903	1904-8	1909-13	1914-18	1919-23	1924-8	1929-33	1934-8	1939-43	1944-8	1949-51
Amber	..	11	3	4	11	17	2	3	1	..	..
Diamond	..	42	13	18	92	36	74	73	1,88	2,53	4,09
Jadeite*	..	9,21	8,31	11,17	14,76	4,45	3,43	1,54	..	..	..
Ruby & Sapphire	..	12,66	9,49	6,27	7,82	3,55	1,01	1,64	..	..	..

OTHER MINERALS

	1,80	1,93	2,45	9	3	..	1	12	41	1,68	1,62
Graphite	96	1,14	2,25	4,93†	12,53
Gypsum	73	4,30	2,22	4,84	35,56
Kyanite	83	1,26	3,27	5,85	14,73
Magnetite	59,37	97,25	2,33,60	3,81,43	9,51,29
Mica	28	1,40	..	84††	..
Monazite	1,19,25	1,12,16	1,15,26	2,92,37	4,85,11
Salt**	10,92	12,21	17,44	6,94†††	31,91
Saltpetre*	83	54	53	32†††	..
Zircon
TOTAL	..	6,38,06	12,58,98	17,73,41	32,35,83	32,22,22	23,30,17	26,30,52	26,88,90	52,45,88	83,38,71

* Export values.

** Prices without duty.

*** Production of metallic tin ceased in 1922.

† Production figures.

†† Estimated value of antimony ore from Chitral and stated value of antimonial lead from Burma for 1939 and 1940 only.

††† Average values of metallic lead and nickel species from Burma for 1939 and 1940 only.

§ Average value of Indian production only, excluding Burma.

§§ Assam and West Punjab fields only.

§§§ Antimony ore from Pakistan (Chitral). Average for 1944, 1945 and 1946 only.

§§§ Chromite figures for 1946, 1947 and 1948 from the Indian Union only.

" Production ceased in 1946. Average for three years only.

" Coal for 1946, 1947 and 1948 from the Indian Union only.

†††† Pakistan not included after 1946.

††††† Averages for two years only. Later statistics have not been published.

†††††† Average of saltpetre exports for 1944 to 1947 inclusive and production figures for 1948.

Note. For more recent figures see Appendix.

new oilfields in the West Punjab and of a great gasfield in Baluchistan, the revival of lead and zinc ore mining in Rajasthan, the smelting of lead ores in Bihar and of antimony ores from Chitral in Bombay, the inauguration of aluminium production, the proof of the continuation of the manganese ores of Madhya Pradesh in depth, the revival of gold mining in Hyderabad, the introduction of modern methods of mining and recovery into the diamond field of Vindhya Pradesh, the discovery of emeralds in Rajasthan, the manufacture of ammonium sulphate on a great scale in Bihar, the production of ferro-alloys in Mysore, the opening of a factory to process the uranium and thorium-bearing rare earth minerals in Travancore, and of another to make titanium white from ilmenite, the growth of the alkali industry and the marked progress of the cement, refractory, ceramic and glass industries. Attention may also be drawn to the proposals to increase the production of pig iron, steel and ferro-alloys of various kinds, to the installation of large oil refineries, to the decision to erect atomic reactors, to the many hydro-electric projects either under construction or contemplated, and to the extended utilization of the ground water supplies of both India and Pakistan. In Burma, it is proposed to explore the coalfields of the Chindwin valley, and the association of the Government of that country with the companies to whom the oilfields and the silver-lead-zinc-copper ore deposits of the Shan States are leased, augurs well for their future progress.

Much remains to be done: great tracts of territory still await detailed geological mapping and prospecting in all three countries, as, for example, in the great mineralized zone of the Himalayas, at present only vaguely outlined from various occurrences of the ores of a number of non-ferrous metals in Sikkim, Nepal, Kumaun, Garhwal, the Kulu valley, Kashmir and Chitral, or, again, in the probable continuation of the wolfram and tin ore-bearing belt of Burma, stretching from Lower Tenasserim through Karenni into the Southern Shan States, and in other areas favourable for ore deposition in the Burma-China frontier tracts. These are by no means the only regions awaiting investigation by the economic geologist. In their own interests, exploratory work of this kind demands initiation, guidance and control by the Governments concerned, if adequately equipped and financed private enterprise fails in the task, for though no single country can hope to be entirely self-sufficient in strategic minerals, there is room for considerable improvement of existing conditions.

In the pages which follow each useful mineral found hitherto in India, Burma or Pakistan is considered individually, its chief occurrences are briefly described, the history of its commercial exploitation is outlined, tables and graphs of production and values are included where necessary, and, with the exception of the commoner metals, its uses in modern industry are explained. Metallurgical processes are considered in cases where they have

been introduced, comparisons made between indigenous and imported articles where they are essential to the proper appreciation of the economic position, and, for the benefit of those on whom the task of searching for new deposits now lies, short notes on the important questions of origin have been incorporated. Both authors of this book have spent many years in the investigation and study of the mineral deposits described and connected subjects, and they are convinced that such knowledge is the surest foundation for successful field work. They also accept responsibility for statements regarding the future development of any particular mineral industry, unless the opinions of others are quoted.

In view of the urgent necessity of increasing food supplies, chapters dealing with the geological aspects of soil formation and of water supplies have been added. The bearing of the former on this problem is self-evident and needs no emphasis: regarding the latter, A. H. Kazni, in a recent report on the Water Supply of Baluchistan, has written: 'There can be no progress in this Province, whether social, educational, economic or otherwise, unless suitable attention is paid to the development of her most precious mineral, water.' The best means of directing such attention are also matters of grave concern in the arid tracts of the Indian Peninsula and in the Dry Zone of Burma. Geologists can render much assistance in the study of such problems and this is the reason for a brief consideration of the principles involved here.

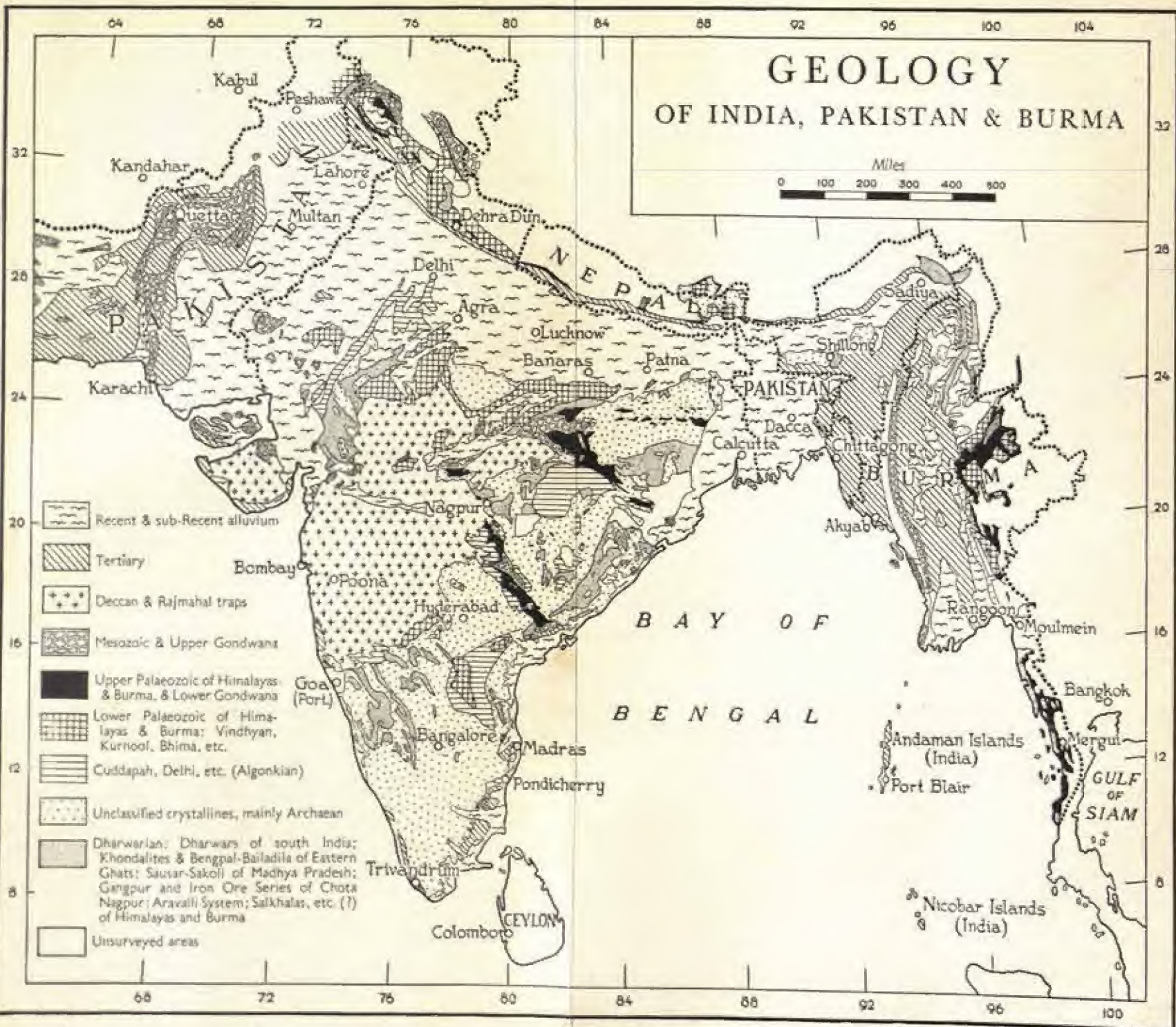
In a conspectus of this kind information has to be drawn from many sources and in case of unintentional omission of acknowledgement in its proper place, our thanks are tendered here to all past and present officers of the Geological Surveys of India, Pakistan and Burma, and to those others whose work has been utilized. To the Chief Geologists of the leading oil companies operating in Burma, Assam and Pakistan, Mr P. Evans and Dr E. S. Pinfold, and their ungrudging help, is largely due the section on petroleum, the most authentic short account of the oilfields concerned yet available. The publication of the book would have been impossible without the official sanction which was kindly obtained for us by Dr W. D. West, to whom and the authorities concerned we are indeed grateful. To Dr West's successor, Dr M. S. Krishnan, Director of the Geological Survey of India, we are particularly indebted for his interest in its preparation and his unfailing assistance in our endeavours to make it as authoritative and up-to-date as possible. In order to supply accurate particulars of the manifold uses of the metals and minerals concerned, including many new applications which have become established during and since the last war, it has been necessary to consult many specialists, manufacturers and Government Departments in India, the United Kingdom, Canada, Australia and the United States, and it is pleasing to record that we have received the fullest co-operation in every instance.

In appendices, besides the latest figures of mineral output, a number of references to literature are given, as they may prove useful to the reader desirous of following a subject further than our limited space permits. In some of these, and in the *Bulletins of Economic Minerals*, published as Vol. LXXVI of the *Records of the Geological Survey of India* during the last war, the Indian producer will find explanations of the manner in which manufacturers are accustomed to obtain supplies of raw ores and minerals, details of the various systems of buying and selling, the regulations of the mineral trade associations, the standard contract forms of metallurgical firms and ore dealers, the recognized market grades and the units of sale. A section of the periodical *Indian Minerals* is regularly devoted to Trade and Commercial Intelligence and to a Review of the Metal Markets. Herein will also be found accounts of new finds as they are discovered as well as digests of scientific and technical progress, both at home and abroad, as it affects the progress of the mineral industry in India and neighbouring lands.

The main object of this book is to draw attention to the commercial and industrial potentialities which the mineral deposits of the three countries possess, in the hope that under administrations aware of their importance, capital and enterprise will be forthcoming in full measure for their future development, with all that it means for the lasting advantage of the peoples of India, Pakistan and Burma.

PART I
THE MINERAL FUELS

MAP 1



CHAPTER I

THE MINERAL FUELS

COAL

COAL is India's most valuable mineral product and its winning one of her more important industries. Over 320,000 workers find employment in and about the mines in normal times and over 98 per cent of the output is consumed in the country. The railways are the largest users and take approximately one third of the total. They are followed by the iron and steel industry, while the remainder supplies power for a host of other undertakings, mills and factories of every description. After the United Kingdom India is the largest coal-producing unit of the Commonwealth; thus her output of approximately 29·7 million tons in 1946 compares with 22 millions from South Africa, 18·3 millions from Australia and 16·7 millions from Canada.

Coal was known to exist in the Raniganj field in 1774 and was actually worked in 1777, though little was done in the way of regular mining until 1814. In those early days the coal was transported to Calcutta by boats on the Damodar river, and the completion of the East Indian Railway to Raniganj in 1855 really created the demand for the fuel. As the railway systems extended, other fields were opened, and by 1881 production had reached about one million tons annually, though the imports of coal into India from abroad still averaged over 800,000 tons for the same period. Rapid expansion followed. Over two million tons were raised in 1890, the export trade began to develop, and by 1900 a yearly output of over six million tons was reached: imports by that time had fallen to about 200,000 tons and exports had increased to nearly half a million tons. (See tables on pp. 75ff.) Later statistics are arranged in tabular form below, and from them it is evident that uninterrupted progress was registered until 1919, with its output of 22,628,037 tons. The decline which then set in following the first world war was due to the cumulative effects of many causes, shortage of railway wagons, inadequacy of labour supplies, prolonged strikes and increasing imports. At the same time the collieries were for a period unable to meet the home demand, and the prices obtained for good coals from 1920 to 1924 were the highest received up to that time: indeed in 1921 the domestic shortage became so acute that exports were temporarily prohibited. Production began to increase again in 1924, and in

1929 and 1930 reached totals of over 23 million tons, when the effects of a world depression in trade spread over the industry. As a result of this, prices slumped to such an extent that the 20 million tons raised in 1932 were worth only half the value at the pit-head of the 19 million tons raised a decade earlier. This state of affairs continued until 1936 and by that time pit-head prices had collapsed to those of the early years of the century. A long overdue improvement was registered in 1937 and from then onwards prices have risen consistently. As the table on p. 75 demonstrates, production of coal has had its fluctuations, but in spite of the unprecedented difficulties of transport and distribution caused by the confused conditions of the second world war, the trend in general has been upwards, reaching 31,695,375 tons in 1949 and 32,307,481 tons in 1950.

Owing to the division of India on 15 August 1947, the coalfields of Baluchistan, the North-West Frontier Province and the West Punjab passed to Pakistan on that date and their production does not appear in the Indian returns from 1947 onwards. For the five years ending 1946, the coalfields of these three regions had contributed an average of less than one per cent per annum to the general total, an amount of little significance to India but of some importance to Pakistan with its coal deficiencies.

The demands on India's coal reserves are great and growing and were estimated by the Indian Coalfields Committee of 1946 as likely to increase to about 41 million tons per annum from 1956 onwards. Amongst other recommendations of this Committee designed to facilitate the required expansion and to reserve the coking coals for metallurgical purposes, the following are noteworthy: the continuation of the Colliery Control Order by which prices and distribution were fixed in 1945; the acquisition by the State of all coal below 2,500 feet, with suitable compensation for working mines; the introduction of various methods of conservation, including the reservation of the coking coals for the use of the iron and steel industry; the prohibition of the export of coking coals and of their use as bunker fuels on steamships; the compulsory introduction of underground sand stowing in mines where it is needed; the use of coals of inferior quality for thermal, electrical power production, and of better-quality non-coking coals in railway locomotives; the systematic investigation of the physical and chemical characteristics of all the known coal seams, and of the problem of the desulphurization of the Tertiary coking coals of Assam; the reorganization of the existing system of the collection of mineral statistics, together with various suggestions regarding the welfare of mining labour and the development of better transport facilities.

India's reserves of coal down to 1,000 feet below the surface, in seams not less than four feet in thickness and containing not more than 25 per cent of ash, are believed to be of the order of 20,000

million tons. Of better-quality coals with not more than 16 per cent of ash, in seams not less than four feet in thickness, there are calculated to be some 5,000 million tons. These estimates refer only to coals of Gondwana age, and, in addition to them, there are reserves of Tertiary coals of the order of 10,000 million tons. As workable coal may be found to extend to depths of 4,000 feet, the actual reserves are probably considerably greater than the figures given. The probable reserves of workable Tertiary coal in Pakistan were computed recently to be 165½ million tons.

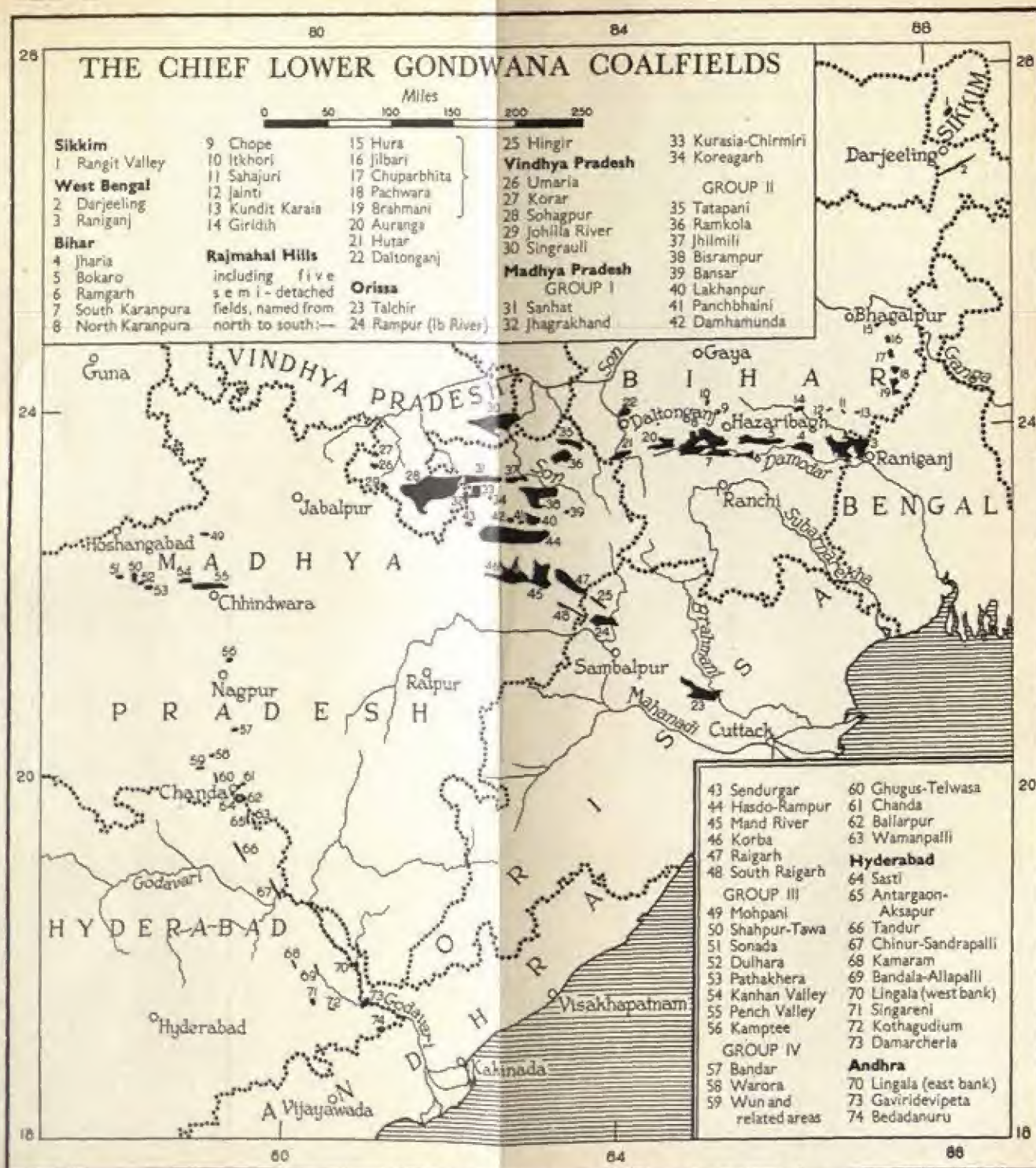
India's reserves of good coking coals, however, give cause for anxiety for most of her Gondwana coals are of non-coking types. The Coalfields Committee estimated the reserves of good coking coals at 700 to 750 million tons, which at the present rate of extraction and wholesale use for all kinds of purposes will be exhausted in some 65 years. Some authorities would double this estimate to 1,500 or 1,600 million tons, adding that by blending weak with strongly coking coals, and careful washing of the inferior grades of coking coals, it should be possible to raise the total to 2,000 million tons. This is the final, overall, most optimistic assessment of the position. In the words of Dr M. S. Krishnan, Director of the Geological Survey of India, however: 'Unless drastic steps are taken to curtail the consumption of coking coal for non-metallurgical purposes, the Indian steel industry will be reduced to the position of having to seek for metallurgical coke from foreign lands.' To this timely warning may be added the unanimous opinion of the members of the Committee on the Conservation of Metallurgical Coke, that the reserves of 2,000 million tons may well be halved unless precautions, particularly compulsory sand stowing, are taken in the mines themselves, and unless those measures of beneficiation already mentioned are adopted with the weaker coking coals when they reach the surface.

The enormous reserves of high-grade iron ores in India, perhaps the largest of their kind in the world, contrasted with the comparatively low reserves of the only fuel by which they can be smelted profitably, have troubled geologists and exercised the minds of the metallurgists of the iron and steel industry for the past thirty years. At present the iron and steel works consume 3½ million tons of coking coal annually, but the country as a whole is burning about 10 million tons of such coal yearly and so reducing the probable life of the reserves to 200 years. Extensions of Indian steel-making capacity, however, are already being built, or contemplated in the not distant future, which will raise its requirements to 8 million tons per annum, so that if used for this purpose alone, the life of the reserves would be some 250 years. But if during the next 50 years steel production is increased tenfold, and as far as iron ore supplies are concerned there is no reason why this should not be done, the coking coal requirements will become 35 million tons per annum, and the probable life of the reserves will then be not more than

55 years. This is a summary of the considered views of the latest Committee of Enquiry into the subject, and they are again followed by a reiteration of the warning that the probable life period may be halved unless the conservation measures recommended are put into practice forthwith.

Fortunately the position is now officially appreciated. Sand stowing of worked-out areas in the mines is widely practised, both as a measure of conservation and on the grounds of safety. Already in 1939, the Coal Mines Safety (Stowing) Act created a Board to administer funds collected for this purpose by the levy of a cess on coal and coke. Wider powers still are conferred on a new Coal Board established under the Coal Mines (Conservation and Safety) Ordinance of 1951, which can now enforce any measures, including stowing, which it considers either necessary or desirable. These, combined with the more general and rational use of the non-coking coals for such purposes as they are best suited, the progress of research into the problems of Indian coal beneficiation by modern methods of washing and blending, together with the fundamentally important work of resurveying and reclassifying the known seams, in which the Geological Survey and the Fuel Research Institute must share, should reduce, if not remove, existing apprehensions. Moreover, it is still possible that scientific research may solve the problem, for it was announced at the Fourth Empire Mining and Metallurgical Congress, in July 1949, that investigations recently made on some of the South African coals, which like those of India are of Gondwana age, have shown that it is possible to produce a satisfactory coke for use in smelting operations from coals which have hitherto been regarded as quite unsuitable for coke manufacture. The coking coals of the quality required by the iron and steel works are found in the Raniganj, Jharia, Giridih, and East and West Bokaro fields; the semi-coking coals come from all these fields, and in addition, from those of Karanpura and the Kanhan Valley. The question of the production of liquid hydrocarbons from coal has received considerable attention in India, particularly in view of her inconsiderable petroleum resources, but the proposal to utilize third-grade, high ash coal for this purpose awaits examination of the high cost factor involved in the initial expenditure on the plant required.

Over 98 per cent of the coal is won from the Lower Gondwana rocks of the Peninsula and the remainder from Tertiary strata of regions outside it. The chief Gondwana exposures are distributed in linear fashion along the valleys of the Damodar and Mahanadi, the Godavari and the Wardha. The former two converge, and coalescing in southern Baghelkhand continue to the west, on the lower side of the Narmada valley, hidden at intervals under the blanket of later Deccan Trap flows, until they finally disappear about Long. 78°. The coalfields are fragments, preserved mainly by faulting, of four great basins of freshwater



deposition which existed over these and probably much more extensive tracts, in Lower Gondwana (Permian) times. One such basin enclosed the areas now drained by the Son, Damodar and their tributaries; a second covered the Chhattisgarh-Mahanadi region; a third the Godavari-Wardha valleys and a fourth the Satpura region. Coalfields of Lower Gondwana age occur thus in the States of West Bengal, Bihar, Madhya Pradesh, Hyderabad, Vindhya Pradesh, Orissa and Andhra (see Map II). As a general rule the coal seams are thick, in some cases exceeding 100 feet. Quarrying on a large scale is done by mechanical methods but mainly on the outcrops of seams of inferior quality. Underground mining has now attained maximum depths of over 2,000 feet, and in the past the bord and pillar system was usually adopted for the extraction of the coal, but the introduction of coal-cutting machines, of which there were over 300 at work in 1947, had led to the adoption of long wall methods at some collieries. Screening plants designed to give marketable products in the eight sizes recognized by the Indian Mining Association are installed at many of the larger collieries. Two large coal washing plants with a capacity of over two million tons of coal per annum were installed for the Tata Iron & Steel Co. Ltd, at West Bokaro in 1951 and Jamadoba in 1952, and another is under construction at Lodna for Messrs Turner, Morrison & Co. Ltd.

Under various enactments full provision is made for the safety and health of the mining labour force. A compulsory provident fund scheme to provide for some 250,000 miners in old age is in operation. A Coal Mines Labour Welfare Fund was instituted in 1944 and derives its income from cesses on both coal and coke dispatches. It is administered under such provisions as housing hospitals and public health of the mining community generally.

The total amount of coal and coke exported from India between 1900 and 1946, inclusive, was 28,694,000 tons, of which Ceylon took 48·3 per cent, the Straits Settlements 14·3 per cent and a number of other countries mainly in eastern Asia under 10 per cent each. The full details of the export trade are tabulated on pp. 80ff. It reached its zenith in 1940 when over two million tons were shipped, mainly to Ceylon, Burma, the Straits Settlements, Hongkong and China. For the five years ending 1948 exports averaged 420,605 tons per annum, the full destinations of which are not available, though with the exception of West Pakistan, which began to import coal from India after the division of the country, they probably did not differ greatly from the earlier and normal ones. In 1949, of an exported total of 1,264,963 tons, Pakistan took 38·5 per cent and Ceylon 24·6 per cent. In 1950 no coal was exported to Pakistan and exports fell to 903,145 tons, of which Ceylon took 32·6 per cent while other destinations included Japan, Egypt, South Korea and Aden. Italy, Libya, Denmark, Argentina and the United Kingdom all received Indian

coal in 1951. The export of coal from India was suspended for a time in 1949 and this gave South African coal, always a serious competitor, unhindered access to the Far Eastern markets. In September 1949 the Government of India took over the control of all export transactions. It is difficult to forecast the future trend of the export trade. India will need her own coking and high-grade gas coals for her own expanding metallurgical and chemical industries. Whether distant foreign markets will accept lower grades will depend in the long run largely on their processing to reliable, standardized grades at competitive prices; in any event geographical proximity to Pakistan and the comparatively short sea leads, as well as long established trade relations with Ceylon, Burma, Malaya and other countries bordering the Indian Ocean, indicate the natural as well as the potential markets of the future should they be required.

The total imports of foreign coal into India between the years 1900 and 1950, inclusive, amounted to 10,669,761 tons, of which 44·7 per cent came from the United Kingdom and 26·7 per cent from South Africa. The statistical data are analysed in the table on p. 79, their most striking feature being the dwindling of the import trade into insignificance at the end of the period. Imports of foreign coal into Pakistan are not included in this table.

A Coal Grading Board, constituted under an Act of the Legislature in 1925, provides for the classification, grading and certification of coal, particularly if it is intended for export. A certificate of the Grading Board is a guarantee of quality for the overseas buyer. The following grades fixed by the Board illustrate the general composition of various kinds of Indian coal.

GRADES OF INDIAN COAL

LOW VOLATILE COAL	HIGH VOLATILE COAL
Jharia (Barakar Series) Giridih Karanpura Bokaro	Raniganj Series Karanpura
SELECTED GRADE	
Up to but not exceeding 13% ash, and over 7,000 calories.	Up to but not exceeding 11% ash, over 6,800 calories, under 6% moisture.
GRADE I	
Up to but not exceeding 15% ash, and over 6,500 calories.	Up to but not exceeding 13% ash, over 6,300 calories, under 9% moisture.
GRADE II	
Up to but not exceeding 18% ash, and over 6,000 calories.	Up to but not exceeding 16% ash, over 6,000 calories, under 10% moisture.
GRADE III	
Any coal from these coalfields inferior to the above.	

During the last war and as a guide to the fixation of prices another classification was adopted. Under its provisions coals of the Raniganj field with ash and moisture content not exceeding 17.5 per cent were classified as Selected Grade A. When the ash and moisture content exceeded 17.5 per cent but did not exceed 19 per cent they were placed in a Selected Grade B, while Grade I coals were those in which ash and moisture combined exceeded 19 per cent but did not exceed 26 per cent. With the exception of those of Tertiary age, Indian coals are usually low in sulphur and phosphorus contents. Typical analyses are given under the descriptions of the separate fields and general ones in the table on p. 75.

India has a population of over 357 millions and Pakistan of some 76 millions, yet it is doubtful if their combined consumption of domestic fuel greatly exceeds one million tons annually. Various efforts have been made to popularize the use of soft coke in place of the traditional fuel of the home, the burning of which in itself constitutes a grievous loss to the agricultural economy, and in 1929 legislation was enacted providing for the levy of a cess on all soft coke dispatched by rail from the coalfields of West Bengal and Bihar. The funds obtained from this cess are used for promoting the sale and improving the methods of manufacture of soft coke, the demand for which is growing in northern India, for while the average dispatches from the two coalfields concerned over the ten years 1940 to 1949, inclusive, were 644,430 tons, they amounted to 1,066,697 tons in 1949 and rose to 1,250,324 tons in 1950.

The production of hard coke for the metallurgical industries, principally iron and steel, exceeded over 2½ million tons in 1941, and for the five years ending 1946 averaged 1,764,373 tons per annum, in making which 2,514,611 tons of coal were consumed. Of this tonnage no less than 93.4 per cent was drawn from the Jharia field, about 4 per cent from Raniganj, 1.4 per cent from Giridih, 1.1 per cent from Bokaro and the remainder from the Namdang Tertiary field of Assam. For the four years ending 1950, the average annual production of hard coke was 1,866,335 tons, representing 2,631,833 tons of coking coal. The production of hard coke in 1950 was 2,103,212 tons. By-product coking dates from about 1910 when the first battery of ovens was erected at the Kulti works of the Bengal Iron Co. Today there are fifteen installations in operation or under construction in India, comprising over 600 ovens, capable of carbonizing some 3½ million tons of coal annually and owned either by colliery companies or by the iron and steel concerns. The coke-oven gas of the latter is used to heat the steel furnaces; of the other by-products, which include benzole and ammonium sulphate, an average of 71,778 tons of coal tar were produced in the five years ending 1950.

The Coal Measures of the Lower Gondwanas are found in the rocks of the Damuda Series, itself the middle of the three divisions

(Talchir, Damuda and Panchet) which form the lower part of the System. The Damuda Series itself is subdivided into three Stages which are displayed in the Raniganj and Jharia coalfields as follows:

SUBDIVISIONS OF THE COAL-BEARING DAMUDA SERIES

RANIGANJ COALFIELD	JHARIA COALFIELD
Raniganj Coal Measures (up to 3,400 feet)	Raniganj Coal Measures (1,840 feet represented)
Ironstone Shales (1,200 feet)	Barren Measures (2,080 feet)
Barakar Coal Measures (up to 2,100 feet)	Barakar Coal Measures (2,000 feet)

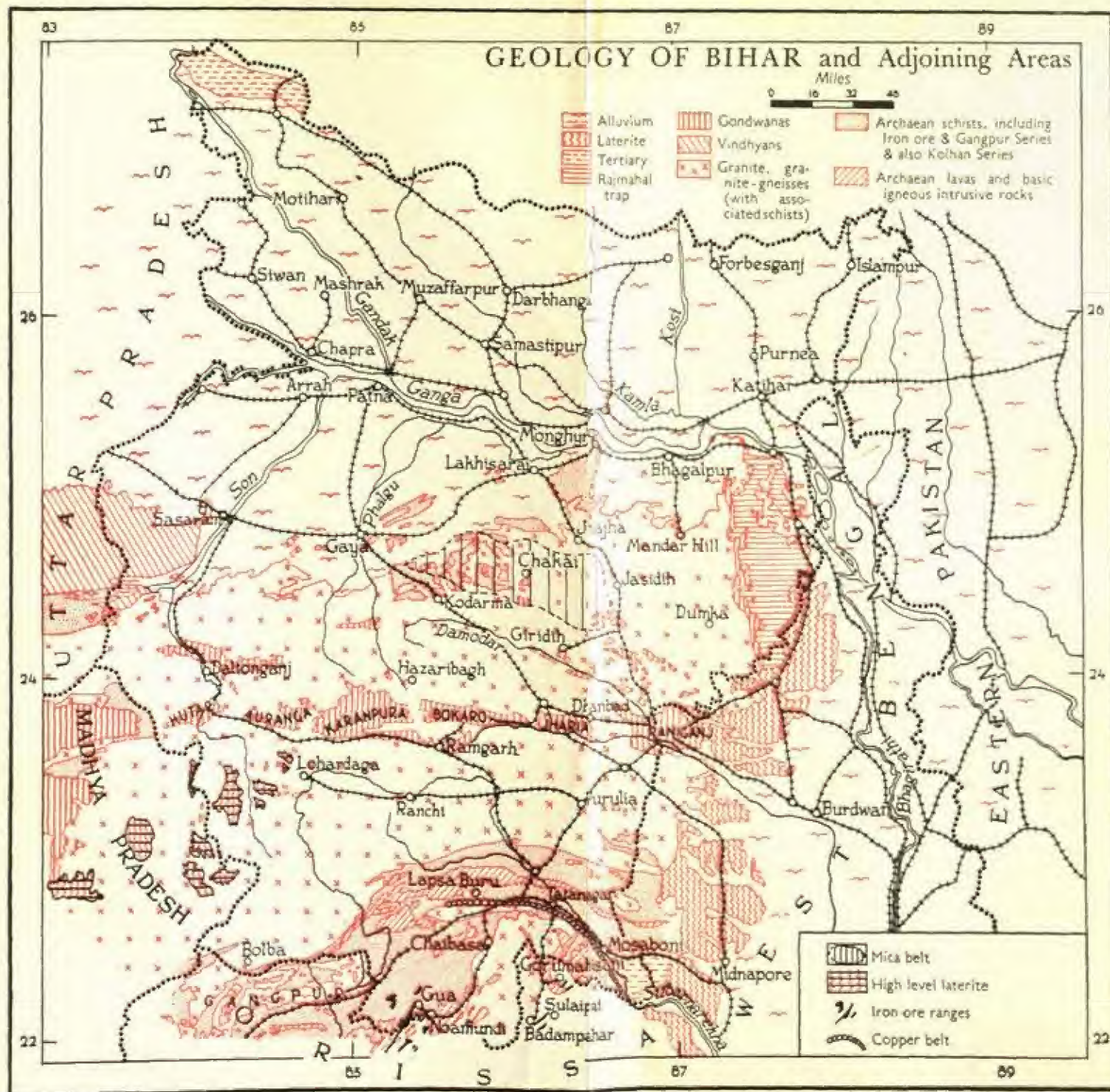
The Barakar Coal Measures of these two fields comprise some 2,000 feet of feldspathic sandstones, conglomerates, clays, fireclays, occasional bands of ironstone and most of the country's important coal seams, and in the central and southern coalfields, not shown in the above table, they vary from a few hundred to over 1,000 feet in thickness. The Barren Measures of the Jharia field are thicker than indicated, if they are taken to include certain beds of both under- and overlying stages which are coal-bearing in Raniganj but not so in Jharia.

Over most of the vast region occupied by this section of the Gondwana rocks in Permian times, the accumulation of the vegetable debris, from which the coal seams were formed, ceased at the end of the Barakar Stage, and the succeeding strata consist of sandstones, shales and ironstones. In the eastern part of what is now the Damodar valley, however, this sequence of barren strata, considerably over 1,000 feet thick, was followed during Upper Permian times by conditions in which coal formation again became possible, represented today by the Raniganj Coal Measures, up to 3,400 feet thick in the type area from which they take their name and which are further represented by a thickness of 1,840 feet in the Jharia field.

The coals of the eastern fields of the Damodar valley have been grouped by E. R. Gee as follows:

(a) RANIGANJ COAL MEASURES (upper and middle seams together with the lower seams of the eastern end of the Raniganj field):—Non-caking to poorly caking, long flame, bituminous to sub-bituminous coals.

(b) RANIGANJ COAL MEASURES (of the Jharia field, together with the lower seams of the western and middle parts of the Raniganj field):—Caking to poorly caking, long flame, bituminous coals.





(c) BARAKAR COAL MEASURES:—Hard-caking, relatively short flame, bituminous coals.

In the fields of the more western parts of the Damodar valley, such as Hutar, Daltonganj and others, the Barakar coals alter in composition and approach those of the eastern parts of the Raniganj field; as such they become long flame, bituminous to sub-bituminous types and possess only poorly caking properties. Such qualities also characterize many of the Barakar seams of the more southern fields of the Peninsula.

Ash percentages under 10 per cent are exceptional for Indian run-of-mine coal and 11 to 13 per cent is the normal figure for best quality coal in marketable quantity. The Barakar seams of the eastern fields contain from 25 to 35 per cent of volatile matter and 65 to 75 per cent of fixed carbon. The Raniganj seams range from 40 to 46 per cent of volatile matter and 54 to 60 per cent of fixed carbon. These percentages are calculated on a moisture and ash free basis. The coking coals of the Barakar Stage are also excellent steam coals, while those of the Raniganj Stage are very suitable for gas manufacture.

The Eocene coals of India and Pakistan possess a lignitic character, except in the case of the Jammu fields of Kashmir where well matured bituminous to anthracitic types occur. Many of the Assamese coals have less than 5 per cent of ash while those of West Punjab and Kashmir usually contain over 10 per cent. Their caking properties vary from strongly caking in the case of Assam to the poorly caking or non-caking coals of West Punjab etc., but unfortunately, most of the Eocene coals possess unusually high percentages of sulphur. As free burning coals, easily pulverized and low in moisture, they have high calorific values and have proved very suitable for cement manufacture.

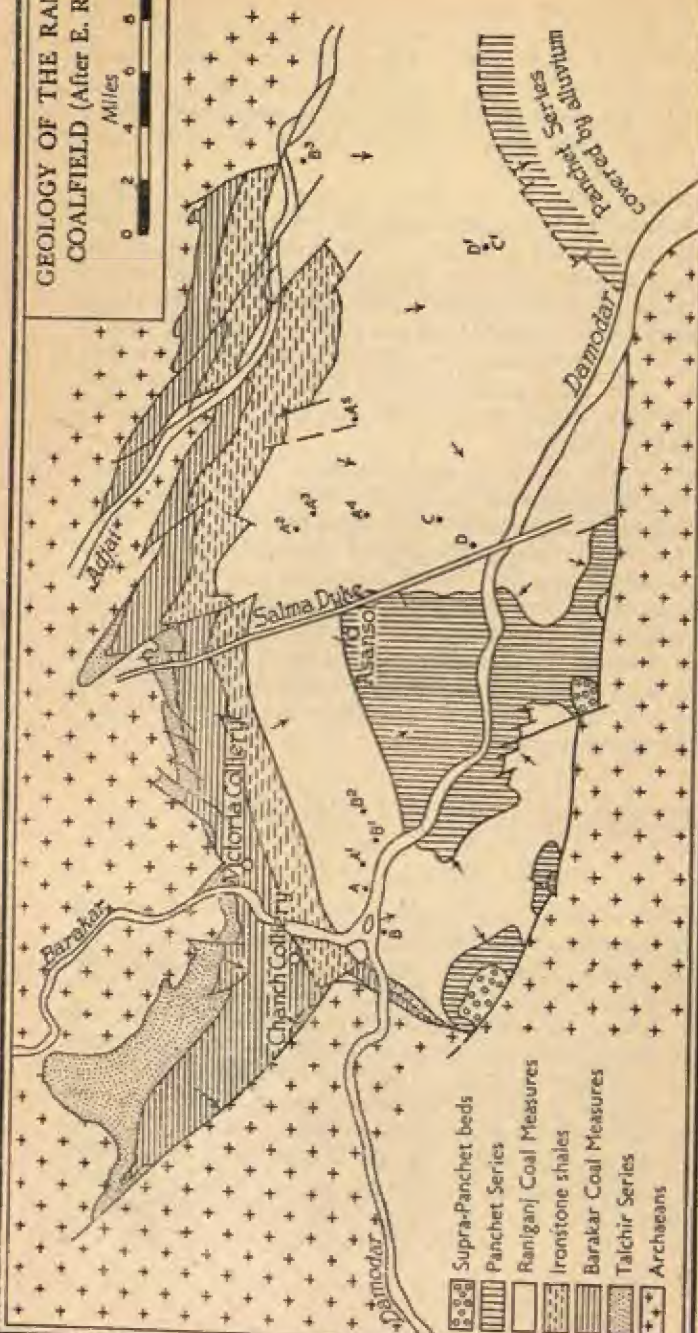
LOWER GONDWANA COALFIELDS

BENGAL, BIHAR, ORISSA

The coalfields of these three States accounted for 86·7 per cent of the 1,022 million tons raised in India between 1900 and 1950, both years included. The major portion of the Raniganj field lies in the western part of West Bengal and smaller parts of it encroach into Bihar. The more important coalfields of Bihar are Jharia, Bokaro, Ramgarh and North and South Karanpura, though there are others of lesser degree. They are all isolated fragments of the once continuous Gondwanaland, faulted down into the crystalline floor and arranged in a broken band stretching roughly east and west along the valley of the Damodar river. Other fragments of Gondwanaland are found in the Mahanadi and Brahmini valleys of Orissa, and although the two coalfields of the State—Talchir, which is partly in Angul, and Rampur, in

MAP IV

GEOLOGY OF THE RANIGANJ COALFIELD (After E. R. Goe)



- Supra-Panchet beds
- Panchet Series
- Raniganj Coal Measures
- Ironstone shales
- Barakar Coal Measures
- Talchir Series
- Archæans

SANCTORIA (Foniat) SEAM

Colliery	H ₂ O	C	O ₂
A. DISHARGARH	1.30	82.2	9.0
A. SITALPUR	2.31	82.5	9.6
A. CHARANPUR	3.42	81.6	10.2
A. BANKSIMPURA	3.60	81.0	11.3
A. SHRIMPUR	2.74	81.2	10.8
A. DAMODARPUR	5.34	79.4	12.0

DISHARGARH & SAMLA SEAMS

Colliery	H ₂ O	C	O ₂
B. SALTOR (D)	1.03	82.0	9.0
B. SODEPUR (D)	2.16	81.7	10.3
B. BODHI (D)	1.99	81.8	10.1
B. SAMLA	1.30	79.2	13.2

NEGA - JAMBAD - BOWLAH SEAM

Colliery	H ₂ O	C	O ₂
C. RATBATHY	5.81	79.6	12.6
C. KHAS	5.10	79.9	13.0
KAJORA	5.10	79.9	13.0

GHUSICK (Upper Kajora) SEAM

Colliery	H ₂ O	C	O ₂
D. RADHA.	3.17	79.6	12.6
D. KHAS	6.47	77.9	14.3
KAJORA	6.47	77.9	14.3

Sambalpur, are now separated, it is certain that the coal-bearing rocks of both were at one time connected. The Rampur coalfield lies at the eastern extremity of a further extension of the Gondwanas, across Gangpur into Madhya Pradesh and Rewah. Brief descriptions of the coalfields now follow.

Raniganj. The easternmost of its group, this coalfield lies from 120 to 150 miles north-west of Calcutta, partly in the Birbhum and Burdwan districts of West Bengal and partly in the Manbhum district of Bihar. It has an area of 619 square miles though its eastern limits, buried as they are under younger strata, are not definitely known. It was the first coalfield to be worked in India, in 1777, and until 1905 was the leading producer. In 1906, its output, then 37 per cent of the Indian total, was surpassed by that of Jharia, with 42 per cent. In 1940 it yielded 9,344,877 tons, or 31·8 per cent of the total, and in 1950, 10,583,885 tons, or 32·76 per cent; its total production up to the end of that year being of the order of 350 million tons.

Its Lower Gondwana rocks are divided in ascending order into the Talchir, Damuda and Panchet Series, and the general classification of the middle, coal-bearing Damudas into the Barakars or Lower Coal Measures, the Ironstone Shales and the Raniganj or Upper Coal Measures has been given on page 10. In the Lower (Barakar) Measures there are seven separate coal-bearing horizons, according to Dr E. R. Gee, whose exhaustive memoir on the field was published in 1932, though they are not all found in every part of the field, while the seams themselves vary greatly in thickness and to a lesser extent in composition, as they are traced from one area to another. The productive seams include the Chanch Laikdih, Ramnagar, Damagaria and Salanpur, which average 20 feet in thickness, and like the others, are known under a variety of confusing synonyms in various parts of the field. The productive seams of the Raniganj Measures are more numerous and in them Gee has correlated nine main coal-bearing horizons. The same disorder of seam nomenclature exists, but the more important ones include the Dishargarh (18 feet thick), Sanctoria or Poniat (10 to 15 feet), Ghusick (10 to 20 feet) and Raniganj (10 to 20 feet).

Coals of Barakar age have relatively low moisture, comparatively low volatile contents ranging from 21 to 30 per cent, and a high proportion of fixed carbon, usually between 52 and 64 per cent, a figure about 55 per cent being common. All the seams of the Barakar Measures are coking coals, while parts of the Laikdih and Ramnagar seams, in particular, yield good, hard cokes: all the better quality seams give good steam coals. In some parts of the field the quality tends to deteriorate owing to a higher ash content, but it should be possible to improve this by suitable cleansing methods.

TYPICAL ANALYSES OF BARAKAR COALS (LOWER MEASURES),
RANIGANJ

SEAM	MOISTURE	VOLATILE MATTER	FIXED CARBON	ASH	FUEL RATIO	CALORIFIC VALUE	REMARKS
Chanch ..	1.63	28.96	56.02	13.39	1.93	..	Strongly caking
Ramnagar	1.61	27.99	58.15	12.25	2.08	7,022	ditto
Laikdih ..	1.58	28.74	60.27	9.41	2.10	7,408	ditto
Laikdih (†)	1.40	26.00	62.00	11.40	2.41	7,632	ditto
Damagaria	1.24	23.00	62.00	15.00	2.70	7,149	Caking

(†) bottom 17 feet of the seam.

Coals of the Raniganj or Upper Measures vary considerably in composition both vertically in the sequence and laterally in individual seams. Compared with the Barakar coals they have, as a rule, more moisture, which ranges from 3 to 10 per cent (though the Dishargarh seam often contains only 1.35 to 3 per cent), and considerably higher volatile contents, varying in the better grades from 29 to 38 per cent: their fuel ratios are in all cases lower than those of the coals from the Barakar Measures. As the seams are followed from east to west of the field there is a progressive increase in moisture content and their caking properties diminish. The Dishargarh and the Sanctoria-Poniat seams yield excellent gas coals and free-burning steam-raising fuels; mixed with a strongly caking Barakar coal they give hard, metallurgical cokes. The remaining seams of these Upper Measures are either non-caking or produce only a very soft coke.

TYPICAL ANALYSES OF UPPER MEASURES (RANIGANJ) COALS

SEAM	MOISTURE	VOLATILE MATTER	FIXED CARBON	ASH	FUEL RATIO	CALORIFIC VALUE	REMARKS
Dishargarh	1.83	35.95	50.54	11.68	1.41	7,074	Gives a hard porous coke
Sanctoria	2.31	34.78	51.07	11.84	1.47	6,983	ditto
Ghusick ..	4.10	33.80	53.50	12.70	1.58	6,791	Poor coke
Raniganj ..	5.81	33.14	45.90	15.15	1.39	6,067	Very poor coke
Jambad ..	5.19	36.98	45.59	12.24	1.23	..	ditto

The Coal Measures of Raniganj, like those of the other fields of the eastern part of the Damodar valley, Jharia and Giridih, were intruded by ultrabasic dykes and sills during the later part of the Mesozoic period, which in many instances have resulted in the production of large quantities of *jhama*, the local name for partially coked coal.

Gee estimated the reserves of the Raniganj field as follows :

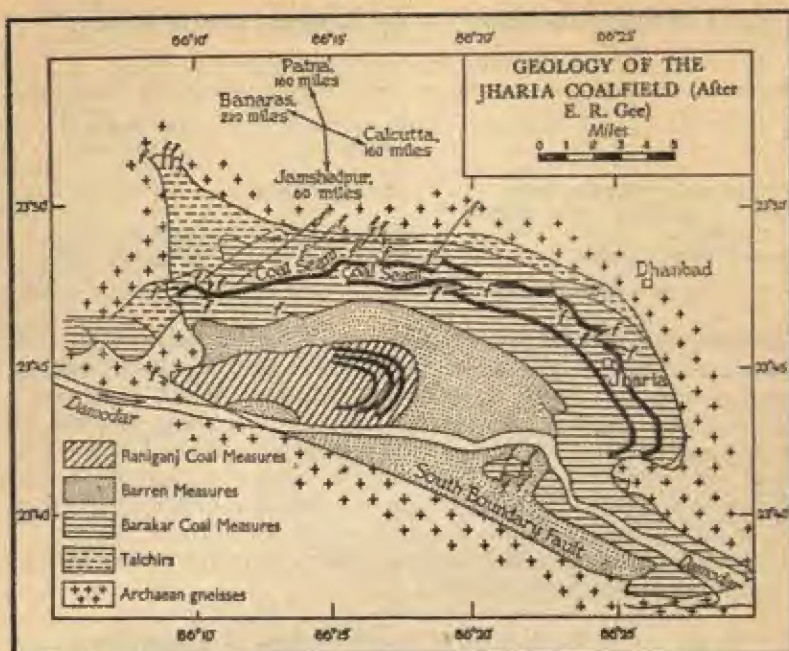
RESERVES OF THE RANIGANJ COALFIELD (1932)

	To a depth of 1,000 feet	To a depth of 2,000 feet
Caking coal of superior quality ..	81,791,000 tons	249,905,000 tons
Non-caking coal of superior quality	953,644,000 "	1,570,730,000 "
Coal of inferior quality	4,631,142,000 "	6,859,291,000 "

The estimates of 'coal of inferior quality' were limited to seams and portions of seams of proved economic value, and the term 'caking coal of superior quality' includes not only coals which yield good metallurgical coke without admixture, but also those reserves of good coal which when mixed with a strongly caking, low volatile coal have proved to yield a good coke. Recent surveys by A. N. Banerjee and others place the reserves of straight coking coal in the Laikdih, Ramnagar and Begunia seams at a round figure of 103,000,000 tons, of which some 84 million tons are recoverable if underground stowing is adopted.

Jharia. The Jharia coalfield, with an area of 175 square miles, of which 105 square miles are occupied by coal-bearing rocks, lies about 30 miles west of the Raniganj field, and although coal was known to occur here before 1858, mining was not undertaken seriously until 1894, when the field became linked to the railway system. From that time production has risen from 15,000 tons to a maximum of 12,692,234 tons, or 39·3 per cent of the Indian total, in 1950, the total yield of the field to the end of that year being 453,461,681 tons, omitting the two years 1895 and 1896, for which separate data are not available.

As in the case of the Raniganj field, the coal-bearing Damuda rocks of Jharia display a threefold subdivision, though with certain important differences. Thus, the Lower or Barakar Measures, about 2,000 feet thick, contain a far greater total thickness of coal, probably exceeding 200 feet, and all of low volatile, coking quality. Secondly, the Ironstone Shales of Raniganj are here represented by a thick series of unproductive sandstones termed the Barren Measures, and thirdly, above these Barren Measures only the lower part of the Upper Measures of the Raniganj sequence occurs in the Jharia field and its coal seams are relatively unimportant by comparison. Intrusions of mica-peridotite dykes are numerous and have burnt many millions of tons of coal into natural coke or *jhama*, which, however, may not be without its economic value in the future. The two groups of Coal Measures are divided into the following Stages.



MAP V

THE BARAKAR (LOWER) COAL MEASURES OF THE JHARIA FIELD

No. 4. BHAGABAND STAGE	700 to 900 feet of strata, the uppermost Barakars. Includes coal seams XVI to XVIII, mainly of superior quality.
No. 3. JIALGARA or BARARI STAGE ..	250 to 300 feet of strata. Includes seams XIII to XV, mainly of superior quality.
No. 2. GAREIRA or NARDKARKI STAGE	300 to 350 feet of strata. Includes seams VIII to XII, of moderate quality, except seam XII which is of good quality.
No. 1. MURAIKH or GOLAKADIH STAGE	500 to 600 feet of strata, the basal Barakars. Includes seams I to VII, mainly of inferior quality.

These Barakar Measures contain not less than 24 separate seams, each with not less than four feet of coal, while many of them are of considerable thickness and often exceed twenty feet. In some cases two thick seams are separated by only a thin sequence of sandstones and shales. In the seams of the Jialgara and Bhagaband Stages there exist some of the best coking and steam-raising coals of the Republic, and until recently the Indian iron and steel industry depended in great measure on cokes made from seams XV, XIV A, and XIV, with XVII and XIII, as well as XVIII, in the order

named. They are 'Selected Grade A' kinds, banded, bright and dull coals of better quality than any other varieties of Gondwana age, with the exception of the coal from the Lower Karharbari seam of the Giridih field. Later it has been found that seams X and XI of the Gareira Stage, as well as XVI and XVII of the Bhagaband Stage, also contain satisfactory coking coal in restricted areas though they generally require careful preparation by washing.

THE RANIGANJ (UPPER) COAL MEASURES OF THE JHARIA FIELD

- No. 4. Lohpiti and Kangra sandstones, thickness 200 feet, uppermost.
 No. 3. TELMUCHA and PATHARGARIA Coal Measures, thickness 200 feet.
 No. 2. Jamdih and Kumardih sandstones, thickness 500 feet.
 No. 1. BAMANGORA and MURULIDIH Coal Measures, thickness 720 feet, basal.

At Telmucha there are three seams, the uppermost being 7 feet thick and the lower ones 3 to 4 feet thick each. In the Bamangora Stage there are seven seams of which three are potentially workable with an average total thickness of 15 to 16 feet.

In 1934, Sir Cyril Fox calculated the reserves of the field as follows:

RESERVES OF THE JHARIA COALFIELD (1934)

SERIES	STAGES	MILLIONS OF TONS AT DEPTHS OF		
		500 ft.	1,000 ft.	2,000 ft.
Upper Measures	Telmucha	17	29	29
	Murulidih	36	61	61
	Bhagaband	115	225	225
Lower Measures	Jialgara	293	568	731
	Gareira	580	1,100	1,550
	Muraidih	630	1,103	1,575
	Extras	36	36	36
	TOTAL	1,707	3,122	4,207

'Making allowances for loss from fires and subsidences, and including the coal left in pillars, it may be broadly stated', wrote Fox, 'that for every ton of coal raised from the seams in question, an equal quantity has been rendered unavailable by existing methods of working.' The 'seams in question' were those of the Bhagaband and Jialgara Stages supplying most of the coking coals, and Fox was driven to the conclusion that at the rate they were then being mined, the reserves of roughly 800 million tons, to a depth of 1,000 feet, must be exhausted within 40 to 50 years, unless mining methods were quickly improved.

Much attention has been devoted to this problem in more recent years and a Working Party of the Geological Survey of India, after making a new computation in 1951, concluded that the reserves of coking coal *in situ* still amount to some 1,200 million tons of Selected Grades A and B (including 325 million tons in unworked areas), and some 766 million tons of Grades I and II (including 85 million tons in unworked areas). It is stressed, however, that without the adoption of stowing as mining proceeds, only 508 million tons of the former and 383 million tons of the latter grades are likely to be won. Even under the best mining practice the losses are likely to amount to one-fifth of the total quantity. As regards reserves of coking coal lying at greater depths than 2,000 feet below the surface, Dr E. R. Gee has suggested that they may be of the order of 1,000 million tons, after allowing for losses caused by igneous intrusions and in mining, but until the results of deep boring tests are available, this question must remain highly speculative.

TYPICAL ANALYSES OF JHARIA, LOWER MEASURES (BARAKAR) COALS

STAGE	SEAM (*)	MOISTURE	VOLATILE MATTER	FIXED CARBON	ASH	FUEL RATIO	CALORIFIC VALUE
Bhagaband ..	XVIII	1.80	24.60	65.00	10.40	2.64	7,608
" ..	XVII A	1.68	26.83	63.30	9.85	2.35	7,634
" ..	XVII	1.70	26.70	62.30	11.00	2.33	7,517
" ..	XVI	2.10	24.35	52.65	23.00	2.16	6,410
Jialgara ..	XV	1.24	22.10	64.66	13.24	2.92	7,693
" ..	XIV	1.08	24.32	60.65	15.02	2.49	7,185
" ..	XIII	0.80	21.20	66.40	12.40	3.13	7,403
Garcira ..	XII	0.90	19.80	62.80	17.40	3.17	7,004
" ..	XI	1.08	20.65	64.47	14.88	3.12	7,291
" ..	X	1.20	20.20	59.40	20.40	2.94	6,681
Muraidih ..	V to VII	1.02	15.15	63.90	20.95	4.22	6,607
" ..	V/VI	0.65	14.20	68.00	17.80	4.79	7,141

(*) The collieries which supplied the 12 samples quoted were, in descending order :—Dharmaband, Baliari, Jamadoba, South Baliari, Lodna, Bhalgora, Banjora, Chetudih, Katras, Kujura, Behaldi East and Matigara North. All the samples are coking coals.

TYPICAL ANALYSES OF JHARIA, UPPER MEASURES (RANIGANJ) COALS

STAGE	SEAM	MOISTURE	VOLATILE MATTER	FIXED CARBON	ASH	FUEL RATIO	CALORIFIC VALUE
Telmucha ..	D.	2.11	28.40	52.80	18.80	1.86	6,607
Muruidih ..	Hatuidih	2.07	32.20	52.75	15.05	1.64	7,084
" ..	Bamangora	1.64	28.75	55.10	16.15	1.92	6,944
" ..	Koradih	2.20	27.68	57.20	15.12	2.07	7,403



V. P. Sinthi, G.S.I.

THE 100-FOOT KARGALI SEAM OF THE BOKARO COALFIELD

The small area of Barakar rocks at the extreme western end of the Jharia field, isolated from it by a narrow strip of Talchir strata, is sometimes referred to as the Chandrapura coalfield. It is but an outlying fragment, less than one square mile in extent, and it contains nine seams with about 10 million tons of coal, mostly of inferior quality.

Bokaro. Two or three miles west of Jharia lies the Bokaro coalfield, occupying an area of 220 square miles in the Hazaribagh district of Bihar, and including a long strip of Gondwana rocks stretching westwards for 40 miles, from Chirudih and in the catchment of the Bokaro river. Its rock sequence includes some 2,750 feet of sandstones and shales of Middle Damuda age, corresponding to the Barren Measures of the Jharia field and like them containing no coal, but they are followed downwards by the coal-bearing Barakar (Lower Damuda) Series, with a total thickness of 2,694 feet. These Barakar rocks were subdivided by Sir Lewis Fermor as follows:

- | | | |
|-----|--------------------------------------|--|
| (d) | Upper Sandstones and Shales. | 982 feet thick with 68 feet of coal in 10 thin seams. |
| (c) | Middle " " " | 863 feet thick with 232 feet of coal in 6 thick seams. |
| (b) | Lower Grits, " " " | 396 feet thick with 25 feet of coal in 7 thin seams. |
| (a) | Basal Grits and Conglomerates. | 128 feet thick. |

Later work has proved that the seams vary considerably from place to place, the most important ones occurring in the Middle Stage (c), and in downward succession comprising the 'A' seam, 12 feet in thickness, the Kargali seam which varies from 41 feet to the enormous total of 123 feet, the Bermo seam from 40 to 46 feet thick, and the Karo seam which is again remarkable for its great thickness of from 70 to 120 feet. In some localities the Kargali seam splits into two sections, separated by comparatively narrow bands of rock. As in the case of the other fields of the Damodar valley already described, dolerite and mica peridotite dykes are common in the Coal Measures. The eastern part of the field has been developed to a greater extent than its western section and very largely by collieries belonging to the State Railways.

By 1910 three collieries were under development in this field and its output jumped from 10,000 tons to almost 200,000 tons per annum on the approach of a railway in 1916, through communication being finally established in 1919. Over one million tons were raised in 1922, or 5.46 of the Indian total for that year. Its highest output was 2,775,286 tons (9.34 per cent of the total) in 1946. In 1950, 1,864,960 tons were won, and the total quantity of coal taken from the field up to the end of that year was 55,598,000 tons, approximately.

Upwards of 90 per cent of the output comes from the Kargali and Bokaro collieries, the property of the Indian Government Railways, and to deal with the extraordinarily thick seams, mechanized outcrop mining has been adopted. On the Kargali seam, which varies from 70 to 110 feet in thickness on this particular property, ten electrically or Diesel-driven excavators operate on a series of four benches, loading directly from the coal face into broad-gauge railway wagons. Besides the Kargali seam, the Karo and Bermo seams, with thicknesses of 120 and 45 feet respectively, occur at these mines.

It has been estimated that in 15 square miles of the Bokaro field there are at least 3,000 million tons of coal of all descriptions, but unfortunately the ash content tends to be high—about 16 per cent in the case of the Kargali and over 27 per cent in that of the Bermo seam, which nevertheless, according to A. B. Dutt, contains some 220 million tons of coal. The Kargali coal can, however, be washed to yield a coke acceptable to the iron and steel makers and its present reserves are estimated to be 583 million tons. Several seams of coking coal are known to occur in the western part of the field, ranging from 9 to 11 feet in thickness, the proven reserves totalling some 88 million tons with an ash content of about 15.6 per cent. A modern coal-washing plant, using the Chance process, is in operation in this section for the Tata Iron & Steel Company. A typical sample of coal from the Kargali seam of West Bokaro contains: moisture 1.6, volatile matter 23.57, fixed carbon 58.96 and ash 16.31 per cent.

Ramgarh. The Ramgarh coalfield, in the Hazaribagh district, lies along the valley of the Damodar river, about 5 miles south-west of Bokaro, and it has an area of some 40 square miles, including 30 square miles of Barakar Coal Measures. Its more prominent seams include the Upper and Lower Ranta, each averaging 20 feet in thickness; the Upper and Lower Sugia, 25 and 15 feet thick, respectively; the Upper and Lower Semabera, 25 and 50 feet thick, respectively; and the Upper and Lower Mael seams, 40 to 60 feet in total thickness. The coals are of medium quality and are said to be of semi-coking varieties. The reserves so far proved total 188 million tons down to relatively shallow depths. Production from Ramgarh first appeared in the annual returns in 1943, and from that time until the end of 1950, 486,397 tons had been won.

North and South Karanpura. A few miles west of the Bokaro field and in the Upper Damodar valley lie the two coalfields of North and South Karanpura, with areas of about 475 and 75 square miles respectively. Mapped by T. W. H. Hughes of the Geological Survey of India, in 1867-8, they were resurveyed by A. Jowett in 1915-18, and the Coal Measures again found to include rocks of

both the Barakar (Lower) and Raniganj (Upper) Series, separated, here as elsewhere, by a thick series of barren strata.

The most important seams occur in the Barakar Series, which in the southern field, lying in the Hazaribagh district, has a thickness of 2,500 feet, of which 280 feet are of coal. Included amongst these seams are the Nakari (7 feet), the Semana (12 feet), the Argada, ranging in thickness from 50 to 120 feet, and the Sirka, which in some cases is 20 feet thick and in others ranges up to 50 feet approximately.

Production commenced in 1925 and rose rapidly with the provision of railway communication to a maximum of 978,695 tons, or 3.25 per cent of the Indian total, in 1947. The total output up to the end of 1950 was 13,494,877 tons. Hughes estimated that 8,750 million tons of coal were available, while according to Jowett, the total quantity of first and second class coal in the Karanpura fields must amount to between 5,000 and 10,000 million tons, to a depth of 2,000 feet. Several open-cast and underground workings have been developed by railway companies and others of late years in the Argada and Sirka seams of South Karanpura. The coal is high in ash—about 20 per cent—but is a useful steaming variety which yields a fairly hard coke. Recent estimates put the reserves of the Argada and Sirka seams at 450 million tons to a depth of 1,000 feet, but they are not included in the official figures of the Republic's reserves of good coking coals.

The North Karanpura field, lying partly in the Hazaribagh and partly in the Palamau district, is known to contain several thick coal seams similar to those of South Karanpura, but remains to be exploited. The economic value of the thin seams of the Upper Measures (Raniganj) of both fields is doubtful.

Chope and Itkhori. Lying to the north of the Karanpura fields and on the Hazaribagh plateau are the two, tiny, unopened coalfields of Chope and Itkhori. The coal-bearing Barakar rocks of the former cover less than one square mile and contain a seam, 4 feet thick, of impure coal. The latter, smaller still, has three seams, one of which is 8 feet and the other 4 feet thick. Hughes estimated the reserves at 1½ million tons of coal.

Sahajuri, Jainti and Kundit Karaia. Forming, as it were, outliers to the great fields of the Damodar valley proper, and actually in the valleys of the Adjai and Barakar rivers, tributaries of the Damodar, are the coalfields of Sahajuri, Jainti, Kundit Karaia and Giridih. The three first-named, in the Santal Parganas, are sometimes grouped together as the Deogarh coalfields and possess a combined area of 28½ square miles, of which 11½ square miles are occupied by Barakar rocks. The opinion of T. W. H. Hughes in the case of Jainti, that in any summary of the coal resources of India it must occupy a very subordinate position, probably applies equally well to all.

Coal was obtained from Jainti in 1886, but organized mining dates from 1914: the record output was reached with 152,941 tons, in 1919 (0.69 per cent of the Indian total): the total production to the end of 1950 was 2,011,751 tons, and that for 1950 alone, 13,710 tons. According to H. S. Dutta, the field contains 5 seams, all of which have been mined at one time or another, while their average thickness appears to be about 5 feet. P. K. Chatterjee, writing in 1934, stated that 2 million tons of good quality coal were then available, of which half is coking coal. The same geologist estimated the workable reserves of the Sahajuri field at 22 million tons, contained in two seams of 18 to 25 feet in thickness, but this coal is inferior in quality and high in ash. The Kundit Karaia field possesses two thin seams of very inferior coal.

Giridih. The Giridih coalfield, in the Hazaribagh district of Bihar, was first brought to notice by McClelland in 1848, and though its area is only about 11 square miles, of which 7 are occupied by Barakar rocks, it has been of great importance by reason of its favourable geographical position and the fact that it yields some of the best coal in India. Systematic mining was initiated in 1851, and its geological survey was undertaken by Hughes in 1868. A railway reached it in 1871 and its exploitation has continued vigorously since then.

The principal seams are the Lower Karharbari, varying between 10 and 24 feet in thickness; the Upper Karharbari, from 4 to 10 feet thick, and the Bhaddoah, averaging about 6 feet. There are other seams with an aggregate thickness of 66 feet, but much of this is of poor quality. The two Karharbari seams have between them provided India with much of its finest metallurgical coking coal in the past. In 1934, Fox estimated the total available coal at about 49 million tons, but as far as good coking coal is concerned, only 17 million tons were left in 1950. For a great many years the whole of the Giridih lump coal was used as locomotive fuel by the railways, while the slack was converted into coke, slack coal from other fields being brought to the Giridih collieries for their own power-raising purposes.

By 1880 the output from the field had reached 400,000 tons and in 1946, at 464,658 tons, it was not much greater: in 1950, 335,581 tons were raised, being 1.04 per cent of the total production. Its record output was 950,045 tons (4.2 per cent) in 1919 and from 1900 to 1950, inclusive, 35,784,440 tons of coal have been taken.

Rajmahal Hills. To the north of the Damodar valley coal measures of Barakar age are exposed over an area of about 70 square miles, in a number of small isolated patches on the western margin of the Rajmahal Hills of eastern Bihar: to the west of them the underlying ancient crystalline floor crops out, while above them to the east are basaltic lavas gently dipping in that direction. They

include Hura, near the northern end of the Hills, with two seams 4 and 16 feet thick respectively; Jilbari, where two seams of poor coal, one of which is 6 feet thick, have been worked spasmodically in the past; Chuparbhita, where several seams up to 9 feet in thickness, but all of poor quality, are known; Pachwara, where coal is won on a small scale for local brick burning; the Mahuagarhi Tract, about which little is known but which presumably contains coal, and the Brahmani field, in which, according to Chakravarti, there are about 29½ million tons of impure coal in a seam with a maximum thickness of 4 feet. V. Ball, as long ago as 1869, calculated that 210 million tons of coal could easily be won from these fields, but Fox concluded in 1934 that the material is not attractive even on a moisture-free basis. Exploitation is confined to the extraction of small quantities of outcrop coal for local uses. The production in 1950 was 1,443 tons, and from 1898 to the end of that year had attained a total of 108,523 tons, omitting the period 1915 to 1918 for which production figures are not available.

Auranga, Hutar and Daltonganj. The main belt of the coalfields of the Damodar valley continues westwards into that of the Koel river and its tributaries, affluents of the Son. These three fields are often referred to as the Palamau group, from the name of the district in which they are situated. Auranga, with an area of over 100 square miles, was surveyed by Ball in 1878 and then by Dunn in 1928, who states that it was described as a 'coalfield' because it consists of Lower Gondwana rocks which contain a few, rare, coal bands. The seams, although up to 40 feet thick, consist largely of carbonaceous shale and the coal itself is so high in ash and moisture that its large-scale systematic exploitation is said to be doubtful. Be this as it may, a colliery, at which operations were started in 1944, supplies fuel to brick works and cement factories.

The Hutar field, 12 miles west of Auranga, covers an area of about 80 square miles, and five seams are known in its Barakar rocks; thin over much of their spread but occasionally thickening to more than 13 feet. One seam, 8 feet thick, of first-class coal is known, but most of the others are of lower grade. Dunn estimated that over an area of 4 square miles, 32 million tons of average, Indian-quality coal are available. Known since 1779, parts of the field have been explored from time to time and it will unquestionably attract more attention in future. The Sone Valley Portland Cement Co. commenced mining at Barichatan in 1946, in two seams which were originally opened up by the Bengal Coal Co. in 1925. The coal, said to contain 31·4 per cent volatile matter, 51·8 per cent fixed carbon and 16·8 per cent of ash, with a calorific value of 6,600 calories, is brought to Barwadih railway station by ropeway for use in the cement works at Japla.

In the Daltonganj field the coal-bearing Barakars crop out over an area of 32 square miles. Coal was known to occur here in 1829,

was mined between 1842 and 1848, and later still by the Bengal Coal Company whose colliery at Rajhara was wrecked in 1857. In those early days the coal was transported by boat down the North Koel river, as a railway did not reach the field until 1901. A boring, 450 feet deep, near Rajhara, penetrated 14 coal seams ranging from 6 inches to 5 feet in thickness, but mining has been limited to the Rajhara seam which locally reaches a maximum of 29 feet. The coal is a non-coking kind and of second-grade quality. As in the case of other semi-explored fields, estimates of its reserves vary widely and the available amounts will not be known definitely until a large-scale geological survey and systematic boring over the whole area is undertaken. According to La Touche (1891) there are about 9 million tons of coal of fair quality in one square mile near Rajhara. For many years production was maintained between 70,000 and 80,000 tons per annum; the record year was in 1908 when 96,391 tons were raised, but output gradually fell away and ceased entirely between 1932 and 1937. Between 1938 and 1950 inclusive, 279,424 tons were won from the two fields of Daltonganj and Hutar. The total production of the Palamau fields between 1900 and 1950, inclusive, was 1,744,930 tons.

Darjeeling. Coal-bearing rocks of Damuda age are found in the Outer Himalayan ranges of the Darjeeling district and of other regions further to the east, such as Bhutan and some of the hilly frontier tracts of north Assam, where, as far as is known, they are of no particular value. Many coal seams, varying in thickness from 2 to 11 feet, were discovered by F. R. Mallet, in 1874, in the 30 miles of country between Pankabari and Daling. The coal itself is in a powdery condition, though P. N. Bose's later researches, in 1890-1, proved that some of it has coking properties. In the Lish valley, near Bagrakot, coal has been exploited since 1943, at an annual rate of 15,000 to 25,000 tons: the production for the four years ending 1950 was 79,022 tons. Thin, steeply dipping seams of powdery coal also occur in the Phagu and Lethi blocks of the Kalimpong Forest Division.

Sikkim. To the north of the Darjeeling district, in the interior ranges of the Lesser Himalaya of western Sikkim, lies the Rangit Valley field in which Coal Measures of Lower Gondwana age extend over an area of 40 or 50 square miles. First visited by T. H. D. La Touche in 1909, the significance of its age was not at that time appreciated and it was not until 1953, when A. M. N. Ghosh published a preliminary account of his investigations, that reliable data of its structure and resources became available.

The field contains several seams, usually from 8 to 12 feet thick, though one, about three-fourths of a mile north-north-east of the confluence of the Rishi *khola* and the Rangit river, attains a thickness of almost 25 feet. The coal, as might be expected from the

intensive mountain-building movements in which these Gondwana rocks have taken part, is of a semi-anthracitic character, an average analysis of eleven samples from various seams showing moisture 3·65, volatile matter 8·13, fixed carbon 57·36 and ash 30·86 per cent. It is non-coking, requires a good draught to commence ignition, burns with a short, smokeless flame, provided a draught is maintained, and has a calorific value varying between 8,730 and 12,335 British Thermal Units with the particular seam tested. According to A. M. N. Ghosh at least 240 million tons are available, assuming a workable thickness of 6 feet.

Although the southern boundary of the Rangit Valley field is only about 6 miles north of Darjeeling, it lies some 6,000 feet below the level of the town and this will necessitate the construction of an aerial ropeway, unless the use of the coal is to be restricted to tea gardens in the neighbourhood of the field.

Talchir. This coalfield, the most easterly member in the Mahanadi-Gondwana zone, lies in the valley of the Brahmani, some 65 miles north-west of Cuttack. The earliest discovery of its coal was announced in 1827, and its first survey was made by the Blanford brothers and W. Theobald, in 1855, with disappointing results, though they have the distinction of forming the subject of the first memoir published by the Geological Survey of India, dated 1856. The field covers an area of at least 200 square miles; its coal-bearing Damuda Series is about 1,800 feet thick, is said to belong to the Barakar Stage, and is overlain unconformably by Upper Gondwana rocks of the Mahadeva Series.

A systematic drilling campaign conducted by Villiers Ltd of Calcutta between 1919 and 1923 proved that the productive seams, at least in the area examined, are confined to the lower section of the Barakar rocks, but only 11 square miles to the west of Talchir town have been thoroughly prospected and found to contain about 184½ million tons of recoverable coal, after allowing for a loss of 40 per cent in extraction. Production commenced in 1923, two seams of 9 and 13 feet in thickness, separated by about 12 to 35 feet of strata, being mined. The record output was 512,375 tons, or 1·74 per cent of the Indian total in 1941: in 1950, 232,440 tons were won and the total amount of coal taken from the field up to the end of that year was 7,113,212 tons. Though comparatively low in ash, the Talchir coals are non-coking and have a high moisture content, but they have proved of practical value for use as locomotive fuels, indeed, the Duelbera (Talchir) colliery has been operated by the Indian Government Railways since 1937.

Rampur-Hingir. The Rampur coalfield forms the central part of the long belt of Lower Gondwana rocks stretching north-westwards up the Mahanadi valley into Madhya Pradesh. Lying as

it does across administrative boundaries which have themselves been changed from time to time, it suffers from a confusing multiplicity of names bestowed on all, or parts of it, both by Government Departments and geologists. Sir Cyril Fox in 1934 proposed to restrict the name Rampur (or Ib River) coalfield to its extreme eastern tip, which now lies in the Sambalpur district of Orissa; to separate a narrow strip of its Barakar rocks on the north as the Hingir field; to name a similar portion of Barakar rocks on the north-west as the South Raigarh field; while the main portion which lies in Madhya Pradesh should, he suggested, retain the name of Raigarh. For present purposes the nomenclature adopted by the Geological Survey of India in its more recent publications is followed. In any case, these separate areas of Barakar rocks are probably continuous under the younger Gondwanas which now superficially divide them.

As a whole the field covers some 200 square miles in Sambalpur and Gangpur (Orissa) and about a further 200 square miles in Raigarh (Madhya Pradesh); the greater part of it has still to be mapped on a large scale and but little is known of its real potentialities. Surveys of part of the area were done by V. Ball in 1871 and 1875, and a series of borings made under the superintendence of W. King between 1884 and 1886 were not particularly encouraging, though thick seams of inferior coal were proved. The accidental discovery of a coal seam during sinking operations for the foundations of the railway bridge over the Ib river led to another survey by G. F. Reader in 1900, when four seams, varying from 4 to 17 feet in thickness, were found by boring. The Ib Bridge seam, however, was the only one with a low enough ash percentage to be worth working. In 1936, Fox calculated that it contains at least 140 million tons of coal within a depth of 600 feet from the surface. Mining commenced in 1929 at the Rampur-Hingir colliery, while a second, the Ib River colliery, began operations in 1940. The highest production was in 1942 with 146,733 tons, while the total amount of coal taken from the field up to the end of 1950 was 2,430,245 tons. Air-dried coal from the Rampur-Hingir colliery has the following composition: Moisture 9.49 per cent, volatile matter 27.74 per cent, fixed carbon 49.19 per cent, ash 13.58 per cent.

VINDHYA PRADESH

The only coal-bearing rocks of Lower Gondwana age within the limits of Vindhya Pradesh are those of the Rewah region, embracing the coalfields of Umaria, Sohagpur, Johilla, Korar and Singrauli. Of the 1,022,364,245 tons of coal raised in India during the first fifty-one years of the present century, 13,572,735 tons, or 1.3 per cent, were derived from the producing fields of Umaria, Sohagpur and Johilla.

Umaria. Deriving its name from the Umrar river, a tributary of the Son, on which it lies 36 miles south-east of Katni, this field was surveyed by Hughes between 1881 and 1884. It has an area of 6 square miles, but its Barakar rocks, which contain six coal seams, dip under younger strata and may be continuous with those of the Korar field, three miles away. Of its six seams, four are workable and range from 3 to 4.5 feet (No. IV), to 8.5 to 13 feet in the case of No. III, but the coal is relatively high both in moisture and ash. Because of its location on the railway between Katni and Bilaspur, the field attracted early attention and mining commenced in 1884. In 1885, its reserves were believed to be 55 million tons, but in 1934 Fox calculated the future available supply at 24 million tons. The record output was 200,285 tons (1.16 per cent of the total) in 1916, but since then there has been a decline, more than compensated, as far as the region as a whole is concerned, by production from Sohagpur and developments on the Johilla field. The output from Umaria in 1950 was 105,603 tons, and the total production from 1884 to 1950 has been 7,439,192 tons, including that from Johilla between 1898 and 1902.

Korar. The small undeveloped field of Korar, surveyed by Hira Lal and Hughes in 1882, has an area of 9½ square miles and lies about 7 miles north-by-east of Umaria. Four seams, ranging from 4 to 8 feet thick, have been proved by boring to a depth of 50 feet.

Sohagpur. Sohagpur is the largest of the coalfields of Rewah and, as mapped by Hughes in 1880, covers 1,600 square miles, but parts of it which cross the borders into Madhya Pradesh have been given separate names. To avoid confusion it has to be borne in mind that the Jhagrakhand coalfield (see page 29) is but the south-eastern corner of the Sohagpur field and that the Sanhat and Jhilmili fields (see pp. 29 and 32) are its eastern extensions into Korea and Surguja respectively. As thus reduced the Sohagpur field occupies about 1,200 square miles in Rewah. Nine-tenths of this extensive area is covered by Barakar rocks, and details of many coal outcrops have been given both by Hughes and by K. P. Sinor (1923). As far as existing information goes it is safe to state that a number of seams of workable thickness exist, some of which are of promising quality, while their low dips and great areal extent lead to the belief that when detailed explorations come to be made the reserves are likely to amount to very large figures. Thus at Rajnagar near Dola in the easternmost end of the field, in an area of 5 square miles leased to Messrs Dalchand Bahadur Singh, a seam 5 to 15 feet thick, with 9 to 10 per cent ash, is estimated to contain about 50 million tons of coal. Another, about 32 feet in thickness, exposed in a small portion of the leased area, is said to contain 12 million tons but the ash content is 25 to 30 per cent.

The south-western part of the field has railway communications, and mining was commenced on a 10-foot seam of the Burhar-Amlel area in 1921. Sohagpur, with an output of 131,174 tons, passed the Umaria production in 1924 and reached its peak of 379,227 tons (1.25 per cent of the total) in 1948. In 1950, 358,988 tons were won (1.11 per cent) and from the beginning to the end of that year its total raisings amount to 5,961,845 tons.

Johilla River Fields. The Barakar Coal Measures occur again in two separate tracts in the valley of the Johilla river, near Birsinghpur, on the Katni-Bilaspur line. The northern area covers $11\frac{1}{2}$ and the southern one $3\frac{1}{4}$ square miles. A few borings in the northern area led Hughes to conclude that at least 20 feet of coal exist, from which 100 million tons might be available within a depth of 500 feet, but this estimate was reduced by Fox to 30 million tons in 1934. Later borings were encouraging; systematic production commenced in 1940 and has steadily increased, reaching 327,592 tons (1.01 per cent of the Indian total) in 1950. The whole recorded output up to the end of 1950 was 1,426,397 tons, omitting the small production over the years 1898 to 1902, included in the Umaria figures.

Singrauli. The area of the Singrauli field, originally surveyed by R. D. Oldham and P. N. Dutta about 1895, and later examined by K. P. Sinor and A. L. Coulson, covers about 900 square miles, extending from Rewah into the south-western corner of the Mirzapur district of Uttar Pradesh. Several coal seams are known to exist, especially near Parari and Naunagar, one of which, originally reported to have a thickness of 18 feet, has recently been found to be 40 feet thick: an exposure located by F. Ahmad, in the Pipraunhi *nala*, displays over 50 feet of coal and may be an extension of the same seam.

Many years ago small quantities of coal used to be extracted and carted to Mirzapur for use on the Ganga river steamers, indeed a small colliery was working near Kota in 1857, but the isolation of the field has hindered its proper exploration let alone development. The reserves of the field will certainly be very large and there is already evidence that some of the coal is of attractive quality. The completion of through railway connexion between Barwadih, to the south of Daltonganj, and Anuppur, on the Katni-Bilaspur line, would enable the Singrauli field to be reached by a short feeder line.

MADHYA PRADESH

The producing coalfields of Madhya Pradesh accounted for 6 per cent of the total Indian production of over 1,022 million tons of coal raised from 1900 to 1950, though by 1950 alone the proportion

had risen to 9.41 per cent of 31,885,096 tons. The fields fall into four natural groups, which include those portions of the Rewah-Gondwana basin stretching across into Madhya Pradesh; those fields lying for the most part in the valleys of the tributaries of the Son, and which form, as it were, a zone joining the western prolongation of the Damodar valley fields to those of the Brahmani-Mahanadi line; the fields of the Satpura region; and, finally, the Wardha valley group.

GROUP I

The accident of a political frontier divides part of the coalfields of the Rewah-Gondwana basin which lie in Vindhya Pradesh from their neighbours in Madhya Pradesh, the State formerly known as the Central Provinces. Coal-bearing Barakar rocks occupy four distinct areas within the boundaries of Korea: they comprise about 416 of its area of 1,647 square miles and are termed the Sanhat, Jhagrakhand, Kurasia-Chirmiri and Koreagarh fields. The two former fields are eastern extensions of the great Sohagpur field of south Rewah.

Sanhat. The largest field of the group with its area of 330 square miles, the Sanhat field occupies the plateau across the central portion of Korea. Surveyed originally by Hughes and Hira Lal in 1885, it was re-examined by Fermor in 1914 and by Coulson in 1923, and although parts of it are leased for mining and others are being prospected, development cannot proceed until railway communication is established. According to K. K. Dutta, about 35 million tons of selected and first-grade coal, 37 millions of second-grade and at least 22 million tons of inferior coal have already been proved.

Included in these estimates are the reserves of certain seams in the Kutkora, Churcha and Sardih sections of the field, which lie on its eastern boundary and about 8 miles further to the west, respectively. The first-named has a seam of $4\frac{1}{2}$ feet separated from a lower one, 13 feet in thickness, by 154 to 164 feet of strata. This lower seam has about 9 million tons of selected grade coal. In the Churcha section, two seams of 4 and 8 feet thickness are capable of yielding 1,700,000 tons of selected coal and 1,800,000 tons of a slightly lower grade. In the Sardih section about 6 million tons are available from a seam approximately 12 to 14 feet thick, assuming a workable thickness of 6 feet. It is anticipated that further prospecting will increase these estimates greatly.

Jhagrakhand. The Jhagrakhand field includes some 30 square miles of Barakar rocks in the south-west of Korea, which are continuous north and west with strata of the same age in the main Sohagpur field. Coulson, who surveyed it in 1923, described three coal-bearing horizons, the lowest of which, extending over 4 or

5 square miles, he believed contained 30.8 million tons of good coal per square mile, in seams of 4 and 6 feet thickness. The coal of the second horizon was of lower grade, while the lateral extent of the highest one was limited and its seams thin. According to K. K. Dutta, there are only two seams, of which the lower, 5 to 7 feet thick, is of superior quality and workable below an area of almost 7 square miles. Some 36 million tons of selected and first-grade coals have already been proved in a portion of the northern section of the field. Both the Jhagrakhand and the Kurasia-Chirmiri field, described below, are now in an advanced stage of development and are served by a feeder line from Anuppur on the Bilaspur-Katni branch of the Eastern Railway.

Kurasia-Chirmiri. In 1884, Hughes gave the name Kurasia to the detached area of 50 square miles of coal-bearing Barakar rocks lying within Korea, 4 to 6 miles south of the Sanhat field; today the field is also called the Chirmiri, after the Chirmiri Colliery started in 1930. Fernor, after a detailed examination in 1915, wrote of the considerable quantities of excellent coal in the field as well worth the expenditure on boring. This has now taken place and six areas in the field are today leased for exploitation. The most important lease is the Chirmiri Colliery of the Ballarpur Collieries Co. Ltd. It comprises an area of 4.75 square miles and mining commenced in 1930 on a 20-foot seam, which now has reserves of about 85 million tons.

The Gorghela area, about 10 square miles in the south-east, leased to the Tata Iron & Steel Co. Ltd, contains according to the Company's geologists eleven coal-bearing horizons: VIII—'Duman', VIIA, VII—'Kotmi', VIA, VI—'Gorghela', V, IVA, IV—'Loharin', III, II, I. But there are only four workable seams, the Loharin (IV) averaging 5 feet in thickness with 11 per cent ash; the Gorghela (VI) 5 to 11 feet with 13 per cent ash; the Kotmi (VII) made up of a number of bands aggregating about 11 feet in thickness and containing 17 per cent ash, and the Duman (VIII) exposed on the east at an altitude of about 2,150 feet and over with a thickness of about 5 feet and containing 18 per cent ash. Tata's Lachman-Jharia lease in the north-eastern part of the field has an area of about 2.5 square miles and contains only two important horizons: the Lachman-Jharia (VIA) of 3 feet thickness with 18.5 per cent ash and the Bijora (VIIA) containing 8 to 17 feet of coal in two bands separated by a parting of sandstone or shale, 1 to 7 feet in thickness; the ash content of the Bijora seam is about 14 per cent. The total reserves of coal available in the Gorghela and Lachman-Jharia areas are of the order of 40 million tons. North of Tata's Lachman-Jharia lease, three seams, 7½, 6½, and 4 feet thick respectively, are exposed in the Tipkapani *nala*, and according to K. K. Dutta at least 7.5 million tons of coal are available here. In the Kurasia Colliery, a sub-lease from Tata's

Gorghela and originally held by the Bombay, Baroda & Central Indian Railway Company and now by the Government of India and producing since 1932, there are three seams: Nos. 1, 2 and 3 from the top, with thicknesses up to 4, 11 and 23 feet respectively, in an area of about 1.25 square miles. The coal generally is of first-class to selected grade in quality, with 9 to 13 per cent ash, and the total reserves available at the time of writing were of the order of 40 million tons. The Chitajhor area (West Chirmiri Colliery) of 1,792 acres in the north of the field, held under lease by Indra Singh & Sons Ltd, has a seam 10½ to 20 feet in thickness with 11 per cent ash and reserves of nearly 27 million tons. The Bijaurajharia lease (North Chirmiri Colliery) of the United Collieries Ltd has a seam split into three bands with thicknesses of 3 to 4 feet, 7 feet and 4 feet respectively from below upwards, average ash content being 13 per cent and reserves of coal about 30 million tons. The New Ponri Hill Colliery of Sir M. Dadabhoy, producing since 1942, has reserves of almost 74 million tons; and the Sajapahar Colliery of the Central India Coalfields Ltd, which commenced mining in 1945, about 9.5 million tons. The total reserves of the field, as far as they are now known, are 313 million tons, a total which may be expected to rise as development proceeds. The coal is generally selected grade.

Output from the Korea fields, all the coals of which are non-coking, commenced with 3,517 tons in 1930 and increased rapidly to more than one million tons in 1938: the record output was in 1942 with 1,283,356 tons (or 4.63 per cent of the Indian total); in 1950 it was 1,023,570 tons (3.17 per cent), and the total production up to the end of that year was 16,869,412 tons.

Koreagarh. The Koreagarh field, with an area of 6 square miles, lies 3 miles south-east of Kurasia-Chirmiri. Its two, or possibly three, thin seams do not appear to be of much economic importance.

GROUP II

In the next group the coalfields concerned, commencing from the north, are Tatapani-Ramkola, Jhilmili and Bistrampur, sometimes referred to as the coalfields of north-east Surguja, and a number of others sometimes classified as the fields of south-west Surguja and north-east Bilaspur, and including Lakhanpur, Sendurga, Hasdo-Rampur, Mand River, Korba and Raigarh. They lie for the most part in tributaries of either the Son or the Mahanadi, in isolated and inaccessible regions, which caused little attention to be paid to them in the past. The construction of the railway link, however, between Barwadih and Anuppur, commenced in 1947, which will tap many of them, has altered this state of affairs and prospecting has recently become active.

Tatapani-Ramkola. These two coalfields are formed by two separate areas of Damuda rocks, in a tract of Gondwanas situated about 15 miles west of the Hutar coalfield (see page 23) between the Kanher and Rehar rivers, northerly flowing tributaries of the Son, in the north-east of Surguja. As the Barakar Coal Measures of Tatapani in the north are only separated from those of Ramkola in the south by a strip of cover rocks belonging to the Panchet and Mahadeva Series, it is legitimate to regard the two as one compound field.

The Coal Measures crop out over an area of about 100 square miles and they were first examined by Griesbach in 1878-9, but although numerous seams were found, few were of workable thickness or quality. Dr A. L. Coulson traversed them again in 1922-3, as geologist accompanying the Central Coalfields Railway Survey, without finding any better material. In 1951, however, Mukti Nath described a seam, 6 feet thick, one mile west-north-west of Mitgain with the following composition: Moisture 10.98 per cent, Volatile Matter 36.46 per cent, Fixed Carbon 44.06 per cent, Ash 8.50 per cent, Calorific Value 5,911. The possibilities of the field will remain doubtful until it is mapped on a large scale and tested by borings.

Jhilmili. This coalfield, recognized by V. Ball about 1872, described from his notes by Hughes in 1885, and re-examined by Coulson in 1923, forms the eastern part of the Sohagpur field lying within the Jhilmili *tahsil* of Surguja—an area of 71 square miles with its Coal Measures continuous with those of the Sanhat field of Korea (see page 29). In the second edition of this book (1936), after referring to the four coal-bearing horizons then known, and the possible existence of others of good quality, it was stated that no estimates of quantities were possible until the field had been bored.

In the intervening years this has been done and four separate areas in it leased for mining, particulars of the proved seams being tabulated below:

COAL SEAMS OF THE JHILMILI FIELD

LEASE	HORIZON	SEAMS	EXTENT	RESERVE	QUALITY
Baakurpara .. (D. B. Singhi)	I	13-14 feet	5½ sq. miles	75m.	16-18% ash
	II	8-9 "	5½ " "	45m.	16-18% "
	III	5-6 "	4½ " "	24m.	10-12% "
	IV	5 "	6 " "	30m.	10-12% "
	V	7 "	6 " "	42m.	10-12% "
Khadapara .. (N. S. Singhi)	—	—	5 " "	45m.	} ? caking
Kundhour .. (N. S. Singhi)	—	5 "	3 " "	15m.	
Goknai .. (R. S. Singhi)	—	7½ "	3 " "	24m.	
	I	11 "	4 " "	44m.	

The reserves as known at present thus amount to 344 million tons. The Goknai area in the north of the field is not yet fully proved, but there are geological grounds for suspecting the existence of Horizons III to V at depth which, if proved by boring, will add considerably to the reserves.

Bisrampur. In the Bisrampur field of central Surguja, V. Ball, in 1872, found the Barakar Coal Measures extending over 400 square miles with good coal in fair abundance, though in his time it had been known for at least 25 years. Coulson gave a summary of such seams as he saw during his traverse in 1922, but in 1936 it was only possible to state the obvious facts that a detailed geological survey and borings were necessary before any reliable estimates could be made.

During the years 1945-7, the Tata Iron & Steel Co. Ltd prospected an area of 180 square miles round De jagir, Khargaon, Badauli, Patpahari and Pasang, and found the following sequence of coal horizons: De jagir, Bedra, Barbaspur, Khargaon, Tulsi, Banki-Raima and Badauli. The last one is referable to the Pasang and Patpahari horizons on the west and to the Lainijoba and Barkadharia horizons on the east. Only the Badauli, Khargaon and De jagir are workable. The Badauli contains two bands with a sandstone split. The upper band is 14 feet thick and contains 5 to 8 per cent Moisture, 34.24 per cent Volatile Matter, 56.56 per cent Fixed Carbon, 5,922 Calorific Value. The lower one is 4 feet with about 5 per cent Moisture, 37.16 per cent Volatile Matter, 54.64 per cent Fixed Carbon, 8.20 per cent Ash, 5,555 Calorific Value. The Khargaon seam, which is about 5 feet thick, contains 38.44 per cent Volatile Matter, 53.40 per cent Fixed Carbon, 8.16 per cent Ash, 6,546 Calorific Value. The De jagir horizon contains four bands separated by fireclay. The bottom seam is 16 feet thick with an average ash content of 23 per cent, 5,555 Calorific Value. The other three seams have an aggregate thickness of about 14 feet but with higher ash content.

Bansar. A small area of 10 square miles of Barakar rocks, lying 5 miles to the east of Bisrampur, was mapped and named by Hira Lal in 1888-9. It is known to contain at least one thin coal seam and deserves thorough re-examination.

Lakhanpur. The Lakhanpur field lies to the south of Bisrampur, partly in Surguja and partly in the Bilaspur district. It has an area of 135 square miles and was reconnoitred partly by Ball in 1870-1 and partly by Hira Lal in 1887-8. Beyond the fact that several outcrops of coal seams, ranging from 3 to 9 feet thick, have been located, next to nothing is known of its possibilities. Much the same applies to most of the remaining fields of Group II, to be mentioned below.

Panchbhaini. This small area of $4\frac{1}{2}$ square miles of coal-bearing rocks of Barakar age, found and named by Hira Lal in 1885-6, lies to the west of the Lakhanpur field. It contains several seams of good quality coal, up to more than 3 feet in thickness.

Damhamunda. Another small area of about the same size as Panchbhaini, lying further west still and in which Hira Lal located some thin coal seams.

Sendurgar. The Sendurgar field, lying five miles west of the Hasdo river, a tributary of the Mahanadi, in northern Bilaspur, has an area of 20 square miles in which seams of 4 feet and 10 feet thickness are known to occur. Hira Lal was of the opinion that most of the area is underlain by the former seam, but if this is halved, the reserves cannot be less than 40 million tons. The coal is of first-class quality and further exploration is desirable.

Hasdo-Rampur. This coalfield spreads from the Rampur tappa of Surguja, in the Arand (Rer) valley, to beyond the Hasdo river, in Bilaspur, and covering an area of nearly 400 square miles, partly in that district and partly in Surguja, it crosses the watershed of the Son and Mahanadi rivers. To avoid confusion with the Rampur-Hingir field of Orissa (see page 25), it would be preferable to refer to it as the Hasdo field, the name suggested originally by Hira Lal for its greater part. The Coal Measures of its eastern and south-central sections are separated from those of the Mand River and Korba fields by younger rocks, though they are probably continuous beneath this superficial cover. The Sendurgar field lies beyond its western end and the outliers of Damhamunda and Panchbhaini are situated to the north between it and the Lakhanpur field. E. R. Gee, writing in 1945, recalls that our knowledge of this field is very limited. Several coal seams of workable thickness and variable quality have been observed, but samples from outcrops are not reliable guides to true composition. 'Further investigations', adds Gee, 'are obviously necessary to obtain anything like a true picture of the position'.

Mand River. The Mand River field lies to the north-west of the Rampur-Hingir field (see page 25), the Supra-Barakar rocks separating them having a minimum width of but 8 miles. It derives its name from that of the tributary of the Mahanadi which bisects it from north to south, and it has an area of roughly 200 square miles. Mentioned by Blanford in 1870, explored by Ball in 1882, and bored in preliminary fashion by W. King and Hira Lal in 1886, it is known to possess a large number of coal seams, but owing to the high ash contents of two of them, the Jubilee Seam, 19 feet thick and the Hira Lal Seam of 13 feet, investigations then ceased and attention was directed to the Korba field.

Korba. A ridge of Supra-Barakar rocks, under which the Coal Measures are doubtless continuous, divides the valley of the Mand river from that of the Hasdo, the next large tributary of the Mahanadi, 16 miles further west. This stream traverses the Korba coalfield, which also extends into the valleys of its tributaries, the Aharan and the Kurung, while a narrow strip of Barakars on the south directly unites it with the Mand River field.

It covers an area of over 200 square miles, and in 1870 Blanford had already found an outcrop exposing 50 feet of coal of good quality. Lala Hira Lal examined the field in 1886-7, when several borings were made. In more recent years it received further attention from prospectors, both Indian and European, but it remains undeveloped though barely 24 miles from the main line of the Bengal-Nagpur railway. At Korba itself a 70-foot seam crops out on the right bank of the Hasdo just below the town, but available analyses of its alternations are not encouraging. A seam, 150 feet thick, has also been recorded 8 miles to the west of Jatraj, itself on the west bank of the Hasdo, south of Korba, and at other places. A 5-foot seam of coal of good quality has been found near Ghordewa, and another, 20 feet thick, to the north-east of the same place. East of the Hasdo, a seam at least 6 feet in thickness exists near Rajgamar, the outcrop samples of which contained under 10 per cent of ash. There are known to be at least 50 million tons of good coal available within quite a small area, while the lower-grade reserves must total many hundreds of millions of tons. The field appears to be singularly free from dislocations and no igneous intrusions have been reported.

The small amounts of coal appearing under 'Bilaspur' in the annual Mineral Returns, over the nine years 1941 to 1949, and reaching a total of only 20,383 tons, probably come from small outcrop quarries on this field.

Raigarh. As explained on page 26, Raigarh is the name given to that portion of the Rampur-Hingir field of Orissa which crosses the border into the north-eastern corner of the Raigarh district of Madhya Pradesh, in which it occupies about 200 square miles. It was examined by V. Ball in 1871, and again in 1875, but most of the seams he found were thin and associated with carbonaceous shales. It has not been bored and must await detailed examination before its resources can be properly assessed. Small amounts of coal have been taken from it since 1933, usually at the rate of 2,000 or 3,000 tons yearly, the highest amount being 3,898 tons in 1940. In 1950, this had fallen to 2,358 tons, and the total recorded production up to that time was 38,683 tons.

South Raigarh. This is a narrow strip of Barakar rocks south of the Raigarh field and contains so far as known poor-quality coal.

GROUP III

Between the isolated Mandla mass of the Deccan Trap in the east and its main great expanse on the west lie the Gondwana rocks of the Satpura basin, in which the Coal Measures appear at intervals from under the margins of the younger groups, over a distance of 170 miles; particularly on the north near Mohpani, in the Narsinghpur district, and in the south in Betul and Chhindwara. The coalfields concerned are the following: Mohpani, in the Narsinghpur district; Shahpur, in the Betul district and the fields of the Tawa, Kanhan and Pench valleys; Tawa lying partly in Betul and partly in Chhindwara district, as well as in the Narmada basin, while the others are in Chhindwara and belong to the Godavari river system. Further south there is abundant evidence of a concealed coalfield near Kamptee in the Nagpur district.

Mohpani. The exposed Barakar Coal Measures of this, the most northerly field of the group, cover rather more than one square mile. Discovered by J. R. Ouseley in 1835, mining commenced in 1862 and continued in the four seams of an area known as the Old Field until 1902, the total amount raised being 450,845 tons. In 1892, a second area, the New Field, was discovered as a result of the work of F. L. G. Simpson and T. D. La Touche, in which seams, aggregating 27 feet in thickness, spread over a considerable expanse. Up to the end of 1903, when the mines were sold by the Nerbada Coal & Iron Co. Ltd to the Great Indian Peninsula Railway Co. Ltd, the output from this had been 181,080 tons, and from that date until operations ceased in 1926, a further 1,402,987 tons had been won. The highest production was reached in 1921, with 89,623 tons, or 0.47 per cent of that year's total. The coal was somewhat inferior in quality to the average Damodar valley coal, and for locomotive purposes $1\frac{1}{4}$ tons of Mohpani coal were taken as equivalent to 1 ton of Bengal coal. It was probably this economic reason which led to the closing of the collieries, for although the area of the field is not large, occurring as it does on a faulted anticline of Barakar rocks, there are still, according to Fox, some seven million tons of workable coal left in it.

Shahpur, Tawa, etc. The Shahpur fields, with an exposed area of about 26 square miles, lie in the valley of the Tawa river between Betul and Hoshangabad, and their thin coal seams were first noticed by J. Finnis in 1834. J. G. Medlicott, in 1863, and Blanford in 1868, found numerous narrow seams, and H. B. Medlicott surveyed the region in 1875, but discovered nothing likely to be profitable. Borings in 1881 led to no better results, but later work about 1920, on the Pathakhara field, an area of about 16 square miles of Barakar rocks, in the Ranipur reserved forest of Betul, proved three seams of $4\frac{1}{2}$, 6 and 13 feet thickness respectively, lying within 200 to 450 feet of the surface. According to Fox,

the thickest of these is of fair quality and more or less proved over about 3 square miles, so that allowing a loss of 50 per cent for dykes, faults and waste in mining, he concluded that 15 million tons may be looked on as the available reserve in the southern and eastern portions. E. R. Gee, writing in 1925, concluded as follows: 'This area appears to represent a large tract which promises well to exploiters, certainly the most promising tract, so far as our present knowledge goes, of the Tawa valley coal-bearing strata; considering its nearness, 7 to 10 miles, from the Betul-Itarsi railway, it is surprising that its exploitation has not already been taken up more enthusiastically.'

The remaining small coalfields concerned include Sonada, Gurgunda or Suki River, Mardanpur or Machna River, Dulhara, Bamhanwara-Khapa and Tandsi. Small quantities of coal have been taken from them for local uses at intervals in the past; between 1921 and 1927, 6,001 tons were so removed; and between 1938 and 1943, 20,504 tons appeared in the official returns.

Kanhan Valley. The coalfields of the Chhindwara district lie on the southern flanks of the Satpuras in the valleys of the Tawa, Kanhan and Pench rivers, stretching from close to the Shahpur fields in the west, at intervals in an easterly direction for 50 miles, to a point 10 miles north of Chhindwara itself. They were discovered by Jerdon and R. H. Sankey in 1852, described by W. T. Blanford in 1866, A. Sopwith in 1867 and E. J. Jones in 1887, sampled by G. V. Hobson in 1924 and resurveyed by Sir Cyril Fox and W. D. West in 1923-5. Officially grouped together for statistical purposes as the Pench Valley fields, they are here separated, following the classification proposed by Fox in 1934, under which the Kanhan Valley fields proper include the Damua-Kalichhappar, Ghorawari-Nimkhera, Panara-Jinaur, Datla-Jamai and Hingladevi areas. As in the fields of Betul further west, the coal-bearing Barakars are overlain in some of them by higher stages of the Lower Gondwana succession, notably the Motur clays and sandstones and the Bijori sandstones and shales.

On the first of them, a seam of moderate quality, 10 to 15 feet thick, has been mined at the Damua colliery since 1932, while the Kalichhappar colliery has been in production since 1936, and the Rakhikol colliery since 1939. The second tract forms the eastward continuation of the Damua-Kalichhappar outcrops, and on it both Top and Ghorawari seams are mined and quarried at the Hirdagarh colliery, which has been producing since 1930, and the Ghorawari Kalan colliery where work commenced in 1943. The Ghorawari seam is about 15 feet thick, separated from it by 15 feet of sandstone is another coal seam 10 feet thick, followed in its turn by 45 feet of sandstone and then by the Bottom seam, again 10 feet thick.

Following closely on the Ghorawari-Nimkhera area is the Panara-Jinaur field where the Ghorawari seam again makes its appearance near the village of Panara. It is mined near Jinaur at the Junnordeo colliery where operations started in 1945. The Datla-Jamai area has a colliery at Dongaria and a seam of somewhat poor quality, about 5 feet thick, has been worked on the Hingladevi field near Ghogri.

Kamptee. As long ago as 1867, W. T. Blanford advised the Chief Commissioner of the Central Provinces (Madhya Pradesh) that borings to a depth of 200 or 250 feet within a few miles of Nagpur would settle the question whether the Barakar rocks, which he suspected to underlie the thick alluvial surface deposits, contained coal or not. He also indicated several suitable locations for such trials.

There the matter remained until a few years ago when a 300-foot borehole searching for water, north of Kanhan railway station, near Kamptee, in Nagpur, cut through several coal seams including one 21 feet thick, 81 feet from ground level, in Barakar rocks lying directly below the alluvium. This discovery led to further borings and in two holes just west of Kandri, a few miles to the north of Kanhan railway station, seams up to about 29 feet in thickness were intersected. In these cases lower Kamthi strata intervene between the surface and the coal-bearing Barakar rocks and the seams are at depths of from 75 to 150 feet below ground level. An analysis of the coal from a shaft sunk later in the same neighbourhood shows: Moisture 7.84, Volatile Matter 30.90, Fixed Carbon 38.53 and Ash 22.72 per cent with a calorific value of 9,140 British Thermal Units. Although a minimum of one million tons of coal is assured here, further exploration is desirable on account of the proximity of the concealed field to Nagpur.

ANALYSES OF KANHAN VALLEY COALS

COLLIERY	MOISTURE	VOLATILE MATTER	FIXED CARBON	ASH	CALORIFIC VALUE	REMARKS
Kanhan ..	2.44	30.76	49.58	17.24	6,515	gives a hard coke
Ghorawari ..	2.40	28.66	50.14	18.80	6,348	
Hirdagarh ..	3.20	29.50	50.35	16.95	6,671	fairly "hard" coke
Rakhikol ..	1.22	25.08	54.15	19.55	6,308	soft coke
Junnordeo ..	3.76	29.80	39.96	26.48	5,226	non-caking
Dongaria ..	4.56	29.84	42.46	23.14	5,602	gives a hard coke
East Ghogri	6.10	28.22	41.84	23.84	5,372	non-caking

In the Kanhan Valley as a whole, although three or four coal seams of workable thickness occur, only one, states Fox, is both

thick and of good enough quality for profitable exploitation, and most of the mining has been confined to this, the topmost of the group. Moreover, the whole tract is sliced by parallel faults, so that each property is usually faced with the problem of working a narrow strip of bearing ground between them. Much of the coal has coking properties and is of fair quality generally, though not equal to the first-grade coals of the Raniganj and Jharia fields. A. B. Dutt has recently estimated that in the Ghorawari and Damua-Rakhikol group of collieries alone there are reserves approaching 66 million tons of coal possessing moderately good caking properties. A railway extension reached the valley in 1915 and its production is included with that of the Pench Valley.

Pench Valley. The Pench Valley fields are practically continuous with those of the Kanhan Valley, indeed some of the coal exposures classed by Fox in the eastern end of the latter might equally well be included in the former. The geological sequence is identical, the Barakar Coal Measures, probably 300 to 400 feet thick, being succeeded by a much greater thickness of the Motur sandstones and clays, the equivalents of the Barren Measures of the middle division of the Damuda Series of the Damodar valley of Bihar and West Bengal. The Coal Measures extend in a continuous, easterly trending strip from Barkuhi through Chandameta and Parasia to the Pench river near Chinda, a distance of 11 miles as the crow flies. In addition to this there are disconnected areas of Barakars near Gajandoh, eastwards from Eklaira, near Setia, at Sirgora and other places.

The Barakars, as usual, consist of coarse sandstones, carbonaceous shales, grey shales, seams of shaly coal and of good coal. 'Although several seams of coal occur,' writes Fox, 'only four of these are recognized at present as possibly workable, and only one, near the top of the series, is worked. It varies from 5 to 12 feet thick and occupies a position about 120 to 150 feet below the base of the Moturs. The lower seams occur within 100 feet below the main seam.' Coal was quarried from the outcrop of one of the seams about 1862. Encouraging prospecting operations by private firms and the provision of through railway communication in 1905 were soon followed by systematic mining: the Chandameta and Barkuhi collieries have been in production from that year and today there are many others at work. The principal sub-areas concerned are Barkuhi, where the seam being mined is 6 to 7½ feet thick; Bhandaria-Bhutaria, where the seam includes 8 feet of coal of which the bottom 5½ feet are worked; Chandameta-Dongar Chikhli, where 6 feet of coal are mined, and the Eklaira-Newton Chikhli area. North of Parasia, a bore hole proved 3 seams, 6, 4 and 4½ feet thick respectively, all within 133 feet of the surface. A deeper bore to 375 feet encountered 7 seams, from 3 to 4½ feet thick, without reaching the base of the Coal Measures. In two

square miles of the Barkuhi, Chandameta and Dongar Chikhli area, Fox calculated that 5 million tons of coal are still available; the southern strip, from Bhutaria to Bhandaria, may perhaps include another half million tons, but if the 3 square miles of coalfield concealed under the Deccan Trap between Bhandaria and Gajandoh is included, the additional amount would be of the order of 10 million tons. In the Eklaira-Newton Chikhli area, the same authority placed the reserves at a total of 7 million tons, allowing for losses, adding that there is little doubt that the Coal Measures extend further, within workable depths, 'far out under the Pench river'.

ANALYSES OF PENCH VALLEY COALS

COLLIERY	MOISTURE	VOLATILE MATTER	FIXED CARBON	ASH	CALORIFIC VALUE	REMARKS
Barkuhi ..	7.38	29.98	44.52	18.12	5,649	non-coking
Chandameta ..	7.48	31.24	44.24	17.04	5,688	" "
Dongar Chikhli	9.60	28.94	44.28	17.18	5,544	" "
Eklaira.. ..	6.98	28.47	45.14	19.41	5,668	" "
Newton Chikhli	7.93	31.20	42.82	18.05	5,650	" "
Rawanwara ..	5.55	29.84	49.35	15.26	6,286	" "
Jamui-Datla ..	3.96	29.42	50.69	15.93	6,836	" "

Progress on the Pench Valley fields has been steady from its inception, output rising without a setback to over one million tons (1,117,942 tons, or 5 per cent of the Indian total) in 1934, and thence to a peak of 1,524,818 tons (5.18 per cent) in 1942. After that time somewhat lower figures were recorded until 1948 and onwards, when they rose to the record of 1,659,999 tons, or 5.14 per cent of the total in 1950. From the commencement in 1903 to the end of 1950, 33,331,917 tons of coal have been mined in the Pench and Kanhan Valley fields.

Sir Cyril Fox computed that the coal reserves of all kinds in the Satpura region as a whole—Mohpani to the Kanhan and Pench Valleys—amount to a round figure of 1,000 million tons, though he reduced this academic calculation to 150 million tons of workable coal, in the absence of deep borings along the northern edge of the Pench Valley.

GROUP IV

The Wardha Valley coalfields are situated in the Chanda and Yeotmal districts of Madhya Pradesh and form part of the Godavari-Gondwana zone. R. R. Simpson, at one time Coal Mining Specialist to the Government of India, summarized the occurrences as follows: 'They occupy the valley of the Wardha river for a distance of about 72 miles in a straight line, the total area being

1,600 square miles. The coal-bearing rocks (Barakars) have a thickness of only 250 feet, their distribution is very broken and their surface area small. There appears to be only one coal horizon, and it occurs near the top of the Coal Measures. The thickness of the coal varies from nothing up to 90 feet, the average being about 30 feet. Our knowledge of the fields is almost entirely due to T. W. H. Hughes, who between 1870 and 1876 mapped the area and superintended the boring operations.' In the Chanda district are situated the Bandar, Warora and Ballarpur fields, the last crossing into Hyderabad. In the Yeotmal district there are the fields of Wun and its related areas, while the Ghugus-Telwasa fields lie partly in both districts.

Bandar. The Bandar field, about 6 square miles in area, lies 30 miles north-east of Warora, and four seams of coal of workable thickness are known, as the result of boring, to occur in it. Fox estimated its available reserves to be at least 54 million tons but owing to its isolated location it remains undeveloped.

Warora. The Coal Measures of the Warora basin, which is 62 miles south of Nagpur, are largely concealed by younger rocks and alluvium. Borings between 1870 and 1873 proved two seams, averaging 15 and 12 feet in thickness, only 46 feet apart and within 232 feet of the surface. Collieries were worked between 1873 and 1906 and, after raising about three million tons of coal, had to be abandoned owing to the influx of water, underground fires and a large subsidence brought about by mining both seams at the same time. Hughes estimated the reserves in 1877 as 20 million tons, with probable extensions to the south raising the total to 60 or 100 million tons. The coal is inferior to Raniganj and Jharia coal by reason of its higher moisture and lower fixed carbon contents.

Wun and Related Areas. Across the Wardha river, in the neighbourhood of Wun and other places in the Yeotmal district of Berar, coal has been proved to occur within the Barakar rocks lying beneath the members of the Kamthi Group, mainly sandstones with no coal seams, which are the local representatives of the Panchet Series of the Damodar valley coalfields. Sometimes, however, in this region the Coal Measures lie directly underneath the alluvium. 'On the Wun side of the Wardha', wrote Hughes, 'a much larger area has been tested than on the Chanda side and the coal has been proved to be much less irregularly distributed. An average of 20 feet may be admitted for 20 square miles and 30 feet for 60 miles, making a total of 2,100 millions of tons.' From direct evidence 105 million tons were estimated to occur between Wun and Papur (7 square miles) and 150 million tons in 5 square miles between Junara and Chicholi, all within 500 feet of the surface. Near Pisgaon, 27 to 31 feet of coal were found at a depth

of 77 feet, and at Rajur, 18 to 30 feet of coal, within 160 feet of the surface. The coal is non-caking, high in moisture and contains some 15 per cent of ash. Reviewing the evidence in 1934, Fox concluded that there are 240 million tons of coal in 12 square miles from beyond Pisgaon to Warora, of which half may be considered available.

A colliery commenced working in 1927, after rail communication had been established, but separate production figures for the Yeotmal district do not appear in the returns until 1938, with the exception of the years 1925 to 1927, when an output of 2,355 tons was obtained. The production in 1950 was 23,411 tons, and the total tonnage won from 1939 to 1950, both years included, was 521,244 tons.

Ghugus-Telwasa. Of small extent as far as visible outcrops are concerned, Ghugus-Telwasa is in reality a concealed field occupying an area of about 100 square miles, in which a seam, over 50 feet thick in places, including its shale bands, has been proved at shallow depths. Estimating on what he regarded as a safe figure of 15 feet of coal, Sir Cyril Fox concluded in 1934 that there are 1,000 million tons available, adding 'surely the possibilities render this [area] one of the most attractive for testing'. The Mayo mine was opened here in 1870 but only worked until 1873, when it was abandoned in favour of Warora colliery. New borings were made after the 1914-18 war and with the construction of a railway from Tadali, on the Ballarshah-Wardha line, to Ghugus, new workings were established about a mile south of the old Mayo mine. No. 1 Pit proved 11 feet of coal at a depth of 109 feet—the top of the thick seam, and No. 3 Pit, 17½ feet at 225 feet. These Coal Measures dip to the west under the Wardha river and should be found again in the Yeotmal district. The coal is non-caking and resembles that from Ballarpur in composition; its production is not shown separately in the official returns, being included apparently with that of Ballarpur and Chanda.

Chanda. Although Chanda town itself, the headquarters of the district of the same name, is supposed to lie on Kamthi rocks, there has always been some doubt about it. In any case, borings at Mahakali on the eastern outskirts of the town found 19 feet of coal at a depth of 81 feet, and 26 feet of coal at 120 feet below the surface. A colliery commenced operations here in 1927, and a second one at Babupeth, to the south-east of the town, sometime before 1934. The extent of the Coal Measures is unknown and the production of the mines is not shown separately in the official returns.

Ballarpur. The Ballarpur field lies for the most part in Hyderabad, where it is known as the Sasti field. In 1868, Blanford found a coal seam, 6 feet thick, on that side of the Wardha river,

that is to say in what were then the Nizam's dominions, but borings on the other bank in Indian territory at that time failed to reach it. In 1900, however, in anticipation of the closure of Warora colliery, systematic re-boring was undertaken in the area and two seams, 17 and 14 feet thick, with a sandstone parting of one foot between them, were proved at a depth of 62 feet, at a point opposite Sasti. Nearer Ballarpur and on the other side of some faulted ground, several seams of workable thickness were met with. The first shaft was sunk in 1903 and the second in 1906 when mining at Warora ceased; through railway communication was established in 1908 and the seams at Sasti were also developed, the coal being carried across the Wardha river from the Hyderabad side by an aerial ropeway to Ballarpur. Mining operations have been continuous, the record annual output having been attained in 1933, with 356,344 tons, or 1.29 per cent of India's total for that year. In 1950, 331,012 tons were raised, and the grand total to the end of that year was 8,088,765 tons. It is to be noted that the totals from 1941 to 1946, inclusive, appear in the official returns under 'Chanda', though before and after that period they are classified under 'Ballarpur'.

Covered as it is by younger rocks, the exact limits of the Ballarpur field are not known, but in the 2 square miles proved, there were reserves of 40 million tons in 1934. The total area involved, however, may well be of the order of 200 square miles with a corresponding multiplication of these figures.

Other large tracts of country where further concealed coal-bearing rocks are believed to occur include Wamanpalli, Lathi and Dabha, the southward continuation of the area lying to the south-east of Chanda town.

ANALYSES OF WARDHA VALLEY COALS

FIELD	MOISTURE	VOLATILE MATTER	FIXED CARBON	ASH	CALORIFIC VALUE	REMARKS
Warora ..	10.40	30.40	41.12	18.06	..	No. 2 seam, 15 feet
" ..	9.78	29.60	43.72	16.88	..	No. 3 seam, 10 feet
Wun ..	10.91	35.30	49.30	15.40	6,539	....
Ghugus ..	11.00	34.30	49.58	16.12	6,114	....
Ballarpur ..	9.64	35.35	50.50	14.15	6,371	....

NOTE :—Calorific values are in calories and, being determined on moisture-free samples, are appreciably higher than the true heating values of the coals.

HYDERABAD

Of the 1,022 million tons of coal produced in India between 1900 and 1950, inclusive, Hyderabad was responsible for 38,474,825

tons, or 3.7 per cent. Its Coal Measures form part of the Pranhita-Godavari Gondwana belt, a continuation towards the south-east of those of the Wardha valley region already briefly outlined. They are of Barakar age, occur at numerous localities, but in nearly every case are overlain by younger Gondwana rocks, the Kamthi sandstones and shales, so that their real extent is not known and indeed cannot be delineated until proved by deep and extensive boring. Complications are introduced by the erosion which the coal-bearing rocks suffered to a varying degree before the Kamthi were deposited upon them, and by the faulting which took place afterwards. Strata of Gondwana age—mainly Kamthi sandstones—form a continuous strip through Hyderabad, where they occupy a region covering some 3,800 square miles, into Andhra, where they have an areal extent of about 600 square miles, but in both States exposures of the Barakar Coal Measures are few and far between. The discovery of the coalfields was due to the labours of W. T. Blanford, T. W. H. Hughes and W. King between 1860 and 1880. The producing fields are those of Sasti, Tandur, Singareni and Kothagudium, but there are several other localities in the Adilabad and Warangal districts where rocks of Barakar age come to the surface but which have no coal seams actually exposed, or where fragments of coal have been found in stream beds, derived from outcrops of seams which still have to be located. Though of little economic interest at present, such occurrences are of great geological importance, especially as a guide to future exploration by boring.

Sasti. The Sasti field is a continuation, on the south side of the Wardha river, of the Ballarpur field in the Chanda district of Madhya Pradesh, the coal occurring in two basins between Sasti and Paoni. Part of the area was bored between 1871 and 1874 and coal with an average thickness of 40 feet proved over an area of $1\frac{1}{2}$ square miles, but the shafts at Sasti colliery found only 27 feet of coal at a depth of 78 feet, as the top of the seam had been denuded. A 60-foot seam was also proved at Paoni. Hughes calculated in 1877 that 30 million tons of coal are available in the $1\frac{1}{2}$ square miles mentioned. Systematic mining commenced in 1920, the area having been leased by the Hyderabad (Deccan) Company to the proprietors of the Ballarpur colliery on the other side of the Wardha river. The total production to the end of 1950 was 1,611,557 tons, the highest output being in 1938 when 90,782 tons were raised.

Antargaon-Aksapur. In the south of the Sasti field the Coal Measures disappear below the covering of Kamthi rocks to the north of Rajur, but they appear again some 10 miles to the south-east as a narrow strip, stretching for approximately 12 miles. To this exposure Fox gave the name of Antargaon-Aksapur coalfield,

the latter part of the compound appellation from a small outlier 10 miles further south, which may be continuous with the rest under the Kamthis. Beyond the fact that a coal seam, 6 feet in thickness, crops out in the Wardha river at Lathi Ghat, nothing further is known about the potentialities of this field.

Tandur. Twelve miles south of Aksapur, and still in the Adilabad district, the Coal Measures come to the surface again, outcropping once more as a narrow strip which reaches from beyond Kairgura, south-eastwards through Tandur, to east of Belampalli railway station, with the small outlier of Waripet to the west. The exploitation of this field dates from the completion of the Kazipet-Ballarshah railway, which passes through Tandur, in 1927. Two seams, averaging $6\frac{1}{2}$ feet in thickness and separated by 140 feet of strata, are mined both by inclines and shafts. Production commenced in 1931 with 46,530 tons, attained a peak of 369,421 tons, being 1.26 per cent of the country's total, in 1942, and was 306,654 tons in 1950 (0.95 per cent of the total). From the commencement of operations until the end of 1950, 5,347,054 tons had been raised.

A certain amount of iron pyrites occurs as layers and lenses in the Tandur coal but is picked out by hand on a travelling belt. Otherwise Hyderabad coals are usually low in sulphur and in phosphorus and as a general average contain about 6 per cent Moisture, 24 per cent Volatile Matter, 56 per cent Fixed Carbon and 14 per cent Ash, with a heating value of 6,500 calories.

Chinur-Sandrapali. From the overlap of the Kamthis on to the Coal Measures at the southern end of the Tandur field, to their next appearance at the surface along the same line of strike, to the north-west of Chinur, is a distance of approximately 18 miles, and yet again the Barakars are exposed as a long narrow strip between members of the Talchir Group on the west and the Kamthi sandstones on the east. Striking to the south-east they cross the Godavari into the Karimnagar district of Hyderabad and continue to beyond Sandrapali, a total distance of 16 miles. Fragments of coal are common in the river below the outcrop but the seams whence they are derived remain undiscovered.

From a point above the junction of the Godavari with the Pranhita and to the south and west of the confluence, an expanse of Kamthi rocks, 16 or 20 miles in width, continues across the valley of the Pengadi river for over 70 miles, south-east to below Cherla. 'That coal seams exist in the Barakars below the Kamthis', wrote Sir Cyril Fox, 'cannot be seriously questioned.'

Kamaram. This is the name of a small outlier of Barakar rocks which lies approximately on a line joining the Tandur and Singareni coalfields, 45 miles from the former and 25 miles from the latter as the crow flies. It contains two seams, 9 feet and 6 feet thick,

respectively, containing 1,132,500 tons of coal, but, in the words of W. King, 'ill-placed in every way for its development'. To the east and south-east of Kamaram, coal has been reported from the region between Bandala and Allapalli, in the Kinarsan valley.

Singareni. The Singareni field, in the Warangal district and 146 miles from Hyderabad city, was discovered and described by W. King in 1872. It occupies a narrow strip of Lower Gondwana rocks, sometimes referred to as the Yellandlapad exposures about 12 miles long and 2 miles wide, of which the Barakar Coal Measures cover 9 square miles. King persuaded the Government to prospect this area by boring, and four seams were proved within 50 to 250 feet of the surface. The top one of good coal was 6 feet thick, the second and third averaged 3 feet each; while a very thick bottom seam, the Singareni seam, was also reached. Later borings and actual workings revealed that the Singareni seam is about 70 feet thick, including some variable shale and sandstone bands. Below it follow the New Seam (5 to 8½ feet), the Stone Coal (3½ to 7½ feet), the King Seam (5 to 6 feet of high quality coal), and finally another seam, 2½ feet thick, 340 feet below the Thick Coal and 140 feet below the King Seam. Mining was commenced in the King Seam in 1886, at first by inclines and by shafts after 1894. In that year Saise estimated that it contained 36 million tons: by 1900 the annual production was over 460,000 tons, and ten years later it was more than half a million tons. The peak was passed with 768,420 tons, or 3.28 per cent of the total Indian output, in 1929, and annual tonnages were maintained between one half and three quarters of a million tons until 1941, when with a sudden fall to 154,164 tons, operations on the field ceased 'on the exhaustion of the King Seam'. History does not relate why the Thick Seam was not mined. The coal was a hard, dull, non-coking steam coal largely consumed by railways and mills in southern India, and the total amount raised from 1886 to 1941 was 26,354,733 tons. Small-scale operations started again in 1948, with an output of 14,235 tons, rising to 77,135 tons in 1950, with a total of 149,959 tons for the three years concerned and bringing the grand total for Singareni to 26,504,692 tons.

Kothagudium. In 1925, borings at Kothagudium proved the presence of the Coal Measures under about 150 feet of Kamthi strata, 24 miles east of Singareni, the King Seam lying at a depth of about 400 feet, while the Thick Seam was found to be strongly intercalated with shaly bands. Mining commenced soon afterwards, but in the meantime a railway had reached the Tandur field where preliminary work had been commenced in 1927. For these reasons the Kothagudium colliery was abandoned, only to be restarted again in 1937, when it became apparent that Singareni was approaching its end. Today the workings consist of four

inclines and one shaft and they are connected to Dornakal junction by a branch line. The coal is utilized by railways and other large consumers, besides being distributed in Hyderabad, Bombay, Andhra and Madras. Production quickly increased to 844,598 tons in 1942 (2.87 per cent of the total) but had fallen to 778,717 tons (2.41 per cent) in 1950. Between 1937 and 1946 inclusive, 7,622,494 tons had been raised.

Other Exposures of Coal Measures. Twenty-five miles south-east of Singareni a small exposure of Coal Measures is known to occur on the north-eastern end of the Kanneigiri Hills, near Maddukuru. To the east of the Kothagudium field and some 25 miles from it, Coal Measures appear again on the right bank of the Godavari about Damercherla and Madhavaram; these rocks cross the river into the Totapalle-Gaviridevipeta region of the East Godavari district of Andhra and are dealt with below.

ANALYSES OF HYDERABAD COALS

FIELD	MOISTURE	VOLATILE MATTER	FIXED CARBON	ASH	CALORIFIC VALUE	REMARKS
Sasti ..	12.06	31.76	52.71	15.53	6,148	(*)
Tandur ..	7.25	28.50	55.40	16.10	6,463	(*)
Singareni ..	7.18	28.75	50.30	13.77	5,984	King Seam
" ..	5.86	24.12	55.85	14.17	6,433	(†)

(*) Ash, Volatile Matter (less Moisture) and Fixed Carbon total 100. Calorific values determined on moisture-free samples.

(†) Average composition of a large number of samples as loaded for dispatch.

POSSIBLE COALFIELDS OF ANDHRA

Dr M. S. Krishnan summarized our existing knowledge of the coalfields of Andhra in 1949, and the following brief notes are derived from his writings. (See Bibliography.)

Lingala Area. A small area of Coal Measures occurs around Lingala, in the East Godavari district, immediately south of the confluence of the Talperu river with its parent stream. The discovery of pieces of coal in the river bed in 1857 led to a visit by W. T. Blanford in 1867 and the subsequent location of four seams, three of 2 feet and one of 5 feet thickness. Seventy tons of good coal were removed from a trial pit in 1891. The whole region was mapped in 1944-5 by V. Subramanyam and S. N. Sen of the Geological Survey, who also uncovered a thin coal seam in a prospecting trench. The possibilities of this small field will remain problematical until it is systematically bored. It lies 40 miles north of Bhadrachalam, itself 20 miles by road from the railhead at the Kothagudium colliery in Hyderabad.

Gaviridevipeta (Totapalle). This small field, ten square miles in extent, is a continuation, on the Andhra side of the Godavari river, of the Damercherla and Madhavaram Coal Measures of Hyderabad, where they cover a further 8 or 9 square miles. The village from which it takes its name is situated 15 miles east-south-east of Bhadrachalam on the Kunavaram road. A few shallow borings were made hereabouts in 1871 at the suggestion of W. T. Blanford, and at least one of them cut through a seam of coal, 18 feet thick. Between 1890 and 1895, the Godavari Coal Co. Ltd sank a shaft and extracted 3,576 tons of coal from a 6-foot seam. V. Subramanyam mapped the field under the supervision of Dr M. S. Krishnan in 1944-5, but until deeper boreholes are drilled through to the underlying basement, be it Talchirs or Metamorphic rocks, this too must remain a problematical field.

Bedadanuru. This area has the distinction of containing the most southerly exposures of the Barakar Coal Measures in the Indian Peninsula. Its name-village, in the Polavaram Agency of West Godavari, is 10 miles north-west of Zangareddigudem, itself some 32 miles from the railhead at Ellore. Discovered by W. T. Blanford and examined by W. King in 1871-2, it was mapped by Dr Krishnan and R. N. P. Arogyaswamy in 1941-2, when it was found to cover an elliptical area of about 6 square miles, overlapped from north-west to south by the younger Kamthi rocks, probably as a rather thin covering. Sixteen boreholes were drilled in it under official auspices in 1874-6, the deepest reaching only 356 feet, and six seams of poor-quality, shaly coal revealed. In 1900, five more holes were bored by the Ellore Syndicate, but they appear to have been badly located and added no new information. Four deeper borings, made in 1922-4 by the Hyderabad (Deccan) Co., in the Swarnavarigudam area, through the overlying Kamthi blanket, from one to two miles south of the Barakar outcrops, reached a maximum depth of about 900 feet, but only proved a 10½-foot seam of very poor quality coal, at a depth of 220 feet in one hole, and at 818 feet in another, further down the dip. Other borings have been made in the Koyyalagudam area (in 1923) and in the Yernagudam taluk, near Komatigunta and Gollagudam, in both cases without finding true coal seams. For details of these and their bearings on future exploration Dr Krishnan's work must be consulted. He has concluded that the possible occurrence of workable seams can be settled only by boring down to 2,000 feet.

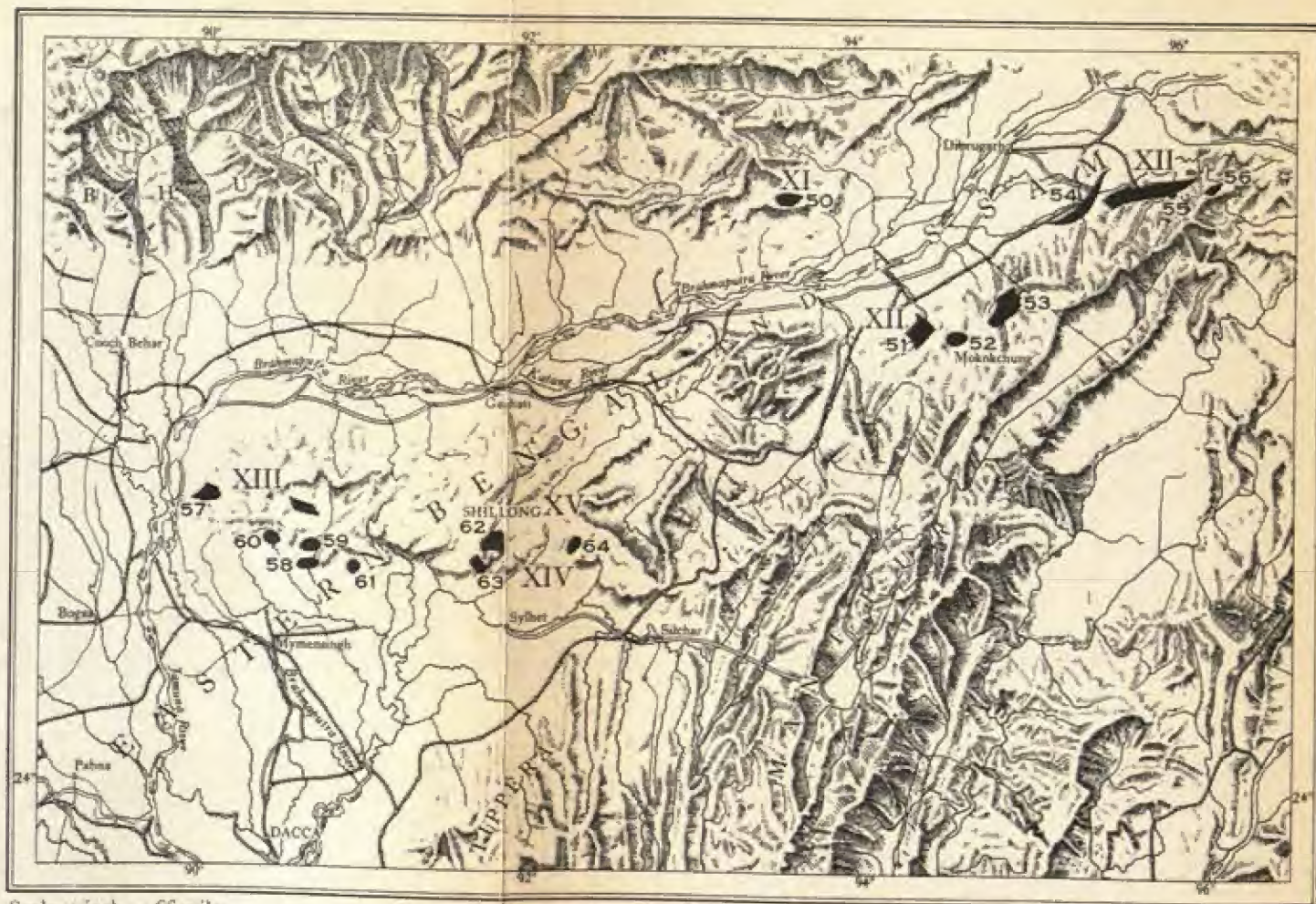
JURASSIC, CRETACEOUS AND TERTIARY COALFIELDS

Although less than 1½ per cent of India's coal is derived from these younger rocks, as compared with the remainder from the Permian Gondwanas, they supply all the coal mined in West Pakistan and their fields are of great economic importance to the

MAP VI

LIST OF FIELDS

- 50 Dikrang
- 51 Disai
- 52 Janji
- 53 Nazira
- 54 Jaipur
- 55 Makum
- 56 Namchik R.
- 57 Harigaon
- 58 Siju
- 59 Daranggiri
- 60 Rongrengiri
- 61 Umblay
- 62 Maobelarkar
- 63 Cherrapunji, etc.
- 64 Lakadong, etc.
- XI Daslas hills
- XII Upper Assam
- XIII Garo hills
- XIV Khasi hills
- XV Jaintia hills



Scale, 1 inch = 66 miles

COALFIELDS OF ASSAM

Brown & Dey, *India's Mineral Wealth*, facing p. 49

After R. R. SIMPSON.

From *Memoirs, Geological Survey of India*, XLI, with Director's permission.

regions in which they occur, and in which mining is done in them, such as those of Assam, Rajasthan, the West Punjab and Baluchistan, while fields still unworked are found in Kashmir and Burma.

ASSAM

Workable coal occurs in Assam at three separate geological horizons, two of which are in the Lower Eocene and the other in the Upper Eocene, possibly extending into the Oligocene. The rocks concerned belong to the Jaintia Series which is about 3,000 feet thick and is well displayed in the southern and south-western portions of the Shillong Plateau region. This series is divided into three stages known, from below upwards, as the Tura Sandstones, the Sylhet Limestones (up to 1,000 feet thick) and the Kopili Beds (1,000 to 1,500 feet). The older geologists classified the Tura Sandstones with the Cretaceous beds of Upper Senonian age which underlie them, when they do not rest directly on crystalline rocks, but they are now thought to belong to the Lower Eocene. They contain important Coal Measures and the oldest of the coal seams of Assam. The Kopili Beds, which are of Khirtar age, also include some thin coal seams: thus coal is found in Assam both above and below the Sylhet Limestones.

The formation of coal during Lower Eocene times was confined mainly to the western areas of the Garo, Khasi, Jaintia and Mikir Hills, but in Upper Assam, along the southern side of the Brahmaputra valley, east of Dibrugarh, it took place in Upper Eocene times, giving rise to the thick seams of the Naga and Patkoi Hills. These Upper Eocene rocks form the Barail Series which occupies a very large area in Upper Assam, showing much lateral variation and necessitating the employment of many local subdivisions as they are followed from the Surma valley, through north Cachar, into the Naga Hills. In the north-east, the subdivisions consist of the lowest or Naogaon Stage, followed by the Bargolai and then by the Tikak Parbat Stages, which together form the Coal Measures and which in their type area are about 11,000 feet in thickness, the thick seams being confined to the lower 400 feet in the Namdang-Ledo area.

THE GARO HILLS

The Garo Hills form the western termination of the Assam Range, around which the Brahmaputra takes its great bend from the Assam valley into the plains of Bengal. Immediately north of the gneissic range, running westwards from the Khasi plateau and forming the culminating ridge of the Garo Hills, the Cretaceous and Lower Tertiary rocks with their Coal Measures occupy a series of detached basins in the gneiss. James Bedford drew attention to the coal of the Garo Hills in 1841, H. B. Medlicott examined

the region in 1864, and T. D. La Touche mapped part of it in 1883. Coal seams have been found in many places, even westwards and northwards of Tura, the chief town of the Hills, for the Tura Sandstones cover large tracts between the Ringgi and Kalu rivers, but the seams of the Karaibara area to the south-west are seldom over 3 feet thick. To the east of Tura and north of the main range, with its peak Nokrek (4,633 feet), are the fields of Rongrenggiri and Daranggiri.

Rongrenggiri. This field lies in the Simsang valley about 20 miles east of Tura, and its sandstones with a cover of Sylhet Limestone extend roughly over 25 square miles, but its seams are described as thin and of no practical value.

Daranggiri. A few miles below Rongrenggiri and on both sides of the Simsang river, above the head of the gorge where it cuts through the main range, lies the Daranggiri field, doubtless connected at one time with its northern neighbour. It is about 10 miles across from east to west, and 6 miles from north to south, with a few outliers to the south. La Touche, in 1883, gave the thickness of the single workable seam as $5\frac{1}{2}$ feet and estimated its contents at 76 million tons above main drainage level. The coal is of excellent quality and R. R. Simpson, writing in 1913, stated that the only bar to its exploitation was its distance from a railway. Its western portion was re-examined by B. Laskar and G. V. Rao in 1949-50, who reported the presence of a main seam $4\frac{1}{2}$ to 5 feet thick of hard, splintery coal, with an upper seam, $1\frac{1}{2}$ to 2 feet thick, some 200 feet higher in the sequence. The main seam dips at very low angles and its reserves, in an area of $18\frac{1}{2}$ square miles, were estimated to be 84 million tons. The eastern portion was examined at the same time by R. N. P. Arogyaswamy, S. N. Sen, A. S. Ramiengar and S. N. Puri who found it dissected into eight small areas as a result of uplift and erosion. They reported little variation in the average thickness of the main seam and estimated its reserves at 31 million tons in 8.89 square miles. The composition of the Daranggiri coal is approximately as follows:—Moisture 8.8 per cent, Volatile Matter 36.3 per cent, Fixed Carbon 49.8 per cent, Ash 5.1 per cent.

Siju. On its southern slopes the main range is flanked by the Lower Eocene strata and the Coal Measures (Tura Sandstones) are visible at many places over the 36 miles between Tura and Siju. R. N. P. Arogyaswamy and A. S. Ramiengar investigated part of this region in 1949-50, locating many exposures between Siju Songmong and Table nala and concluding that reserves of the order of 117 million tons may be expected in 26 square miles, though verification by drilling is recommended.

THE KHASI AND JAINTIA HILLS

Part of the Daranggiri field lies within the Khasi Hills, for the Simsang and its tributary, the Rongdi, form the administrative boundary between them and the Garo Hills to the west. There is no break in stratigraphical continuity and the Coal Measures extend up the Rengchu valley into the Nongstoin area of the Khasi Hills. The Tura Sandstones with their capping of Sylhet Limestone occur on Asilgaon Hill (1,739 feet), where at least two coal seams extend over 3 square miles. The lower one contains not less than 15 million tons of partly coking coal, assaying Moisture 4.65 per cent, Volatile Matter 35.2 per cent, Fixed Carbon 60.4 per cent and Ash 4.4 per cent.

Langrin (Umblay). The gently inclined coal seams of the massif of Pendengru, in the Garo Hills, extend into the extreme south-western corner of the Khasi Hills to form the Langrin coalfield. Mentioned by W. Jones in 1829, visited by Godwin-Austen in 1869 and mapped by La Touche in 1884, it builds a plateau, deeply trenched by several streams, 1,500 feet above the plains to which it descends steeply on the south. It covers about 30 square miles and has at least four seams with an aggregate thickness of 20 feet. No estimates of its reserves have been made but large quantities of coal of fair quality, some of which possesses caking properties, undoubtedly exist.

Other Small Fields. A number of small fields exist in the neighbourhood of Shillong, the capital of Assam, both to the north and south. They include Um Rileng, with an area of half a square mile, where the Tura Sandstones carry two seams, with a total of 8 to 10 feet of coal, and reserves of one million tons in the lower 5-foot seam; and Maobehlarkar, 20 miles south of Shillong, to which it supplied fuel for many years, of small extent and of little consequence. At Cherrapunji, where coal has been known since 1815, small-scale mining has been carried on since 1834. The area of the field is only 136 acres and in 1889 its reserves were estimated at 1,185,000 tons, in a seam varying from 3 to 9 feet in thickness. Other localities in the same neighbourhood include Rongsanoba, Laitrango and Mawlong. Their seams, like those of Cherrapunji itself, occur in sandstones which lie above the Sylhet Limestone and thus belong to the Kopili Stage of the Lower Eocene. As a rule they are strongly caking coals of good quality with a low ash content. Since 1935, Cherrapunji coal has been won by the Cherra-Chhatak Ropeway Co., and transported by ropeway to Bholaganj and thence by boat traffic. In 1884, the output from the field was 4,200 tons, but in the period covered by the official mineral statistics, the whole production of the Khasi and Jaintia Hills never exceeded a few hundred tons per annum, until it reached 1,005 tons in 1930, since when it has greatly increased. In 1950

it was 50,694 tons and the total tonnage raised between 1930 and 1950, inclusive, was 402,747 tons.

THE JAINTIA HILLS

Coal seams of the same age as those just described, and usually 2 or 3 feet in thickness, occur in the Jaintia Hills of central Assam, a region which also includes the north Cachar Hills and continues into the Mikir Hills of south-east Nowgong and west Sibsagar. Amongst other localities are those of Jaram, 10 miles south of Jowai; Bapung, 7 miles east of the same place; Satunga, 15 miles to the east-south-east and Lakadong, barely 10 miles east-north-east of Jaintiapur on the plains of Sylhet. Further east, in the valley of the Kopili, the stream separating the Jaintia Hills from those of north Cachar, and in that of its tributary the Dying, it is known that Eocene coal occurs, but the region has still to be mapped in detail.

THE MIKIR HILLS

Of the eight coal occurrences found in the Mikir Hills by F. H. Smith in 1897, only two are of sufficient thickness to be of economic interest. They are at Longloi, where 12 feet of rather poor coal are visible, and Nambor, where the high ash content renders profitable exploitation improbable. Longloi, in the centre of the south Mikir Hills, is close to the Jamuna river and 12 miles north-north-east of Lumding on the North Eastern Railway. Further to the east, two seams, 3 to 4 feet thick, are known in the Dissoma valley. It is also reported that coal occurs in quantity in the Jahenri and Koliani river valleys, which drain the hills west of Golaghat, in western Sibsagar district. At Koilapahar, 17 miles west-north-west of Manipur Road, in the Mikir Hills of west Sibsagar, a 5½-foot seam is mined at the Koilajan colliery. All the coals of the Mikir Hills belong to the Lower Eocene and probably to the Cherra (Tura) Sandstone Stage.

COALFIELDS OF UPPER ASSAM

Leaving the Mikir Hills and continuing north-eastwards into Upper Assam, the broad valley of the Brahmaputra, bounded on the north by the foot-hills of the eastern Himalaya and on the south by the Naga Hills and the offshoots of the Patkai Range, no further examples of the Lower Eocene Coal Measures are met with, but only those belonging to the upper part of the same system, continuing perhaps into the Oligocene. They form part of the Barail Series—a great thickness of mainly arenaceous beds in which coal first shows its presence as thin, inconstant streaks in the sandstones and as carbonaceous shales. These, however, when followed to the north-east from the Zubza valley, across the valleys of many

other streams which flow from the Naga Hills to unite in the Sibsagar plains and join the Brahmaputra, become more abundant, until in the valley of the Dayang stream, thin coal seams, up to 1 foot in thickness, make their appearance. At Sanis, on the watershed between the Dayang and the Baghti, a 10-foot seam occurs, while at Chohuisan and in the near-by Disai valley, five or six seams, up to 4 feet thick, are known. The extent of the Disai field has still to be determined, but the proven length of coal outcrops is about 5 miles. The coals themselves have the following average composition: Moisture 6.8 per cent, Volatile Matter 33.8 per cent, Fixed Carbon 52.9 per cent, Ash 6.5 per cent.

Further on in the same general direction the following coalfields are known, Jhanzi, Nazira, Jaipur, Makum and Namchik.

Jhanzi. In this field two or three thin seams have been traced for rather less than 3 miles. The occurrence is about 15 miles south-east of Amguri railway station.

Nazira. About eight miles north-east of Jhanzi, lies the Nazira field in which steeply dipping coal-bearing rocks have been followed for 16 miles. This area, drained by the Dikhu, Tiru and Saffrai rivers, was known in 1848, examined by Mallet in 1876 and by Simpson in 1906. Mallet estimated the reserves of the Saffrai portion, over a length of $4\frac{1}{2}$ miles, at an average thickness of 51 feet, in 5 seams, and within 350 feet of the outcrop, at 20 million tons, but these reserves refer only to a portion of the area. The coal is a high-grade, caking variety with Moisture 4.85 per cent, Volatile Matter 39.15 per cent, Fixed Carbon 53.70 per cent, Ash 2.30 per cent, and a Calorific Value of 7,448: as usual with Assamese coals, the sulphur percentage is high. The coal seams in the collieries of Borjan and Konjan are in the lower part of the Tikak Parbat Stage of the Upper Eocene. The mines actually lie in the Naga Hills, but they are connected with the North Eastern Railway at Sibsagar Road station by a branch line 15 miles in length, terminating at Naginimara, to which the coal is conveyed by an aerial ropeway, 4 miles in length, from the workings which are situated about 1,000 feet above the level of the railway. The output from 1913 to the end of 1950 was 1,110,109 tons, the highest production being in 1924 with 60,083 tons, but of late years there has been a marked decline, the annual average for the five years ending 1950 being only 20,843 tons.

Jaipur. After a gap of about 16 miles, across which the Coal Measures have not yet been traced, probably because of the maximum difficulties of prospecting in the virgin forest, dense thorny undergrowth and thick soil caps which the Naga Hills present, they are known again, stretching north-eastwards from the Ti yok stream, across the Disang valley, where they leave the

Sibsagar district and enter that of Lakhimpur, thence across the Dihing for approximately 4 miles beyond Lakhimpur, a total distance of some 25 miles. This band forms the Jaipur field, in the southern portion of which, especially near Barpeta, Disam, Hapjan and Jaipur itself, a town on the railway, the coal seams are of considerable thickness, though north of the Dehing, near Dhekiajuli and Seraipung, they are very much thinner.

Known in 1838, the field for many years supplied the factories of the local tea estates with fuel from outcrop quarries. In 1876, Mallet estimated that between Tipam and Boruarchali, a distance of 15 miles, allowing an average workable thickness of 15 feet, there was a total of 20 million tons of coal within a depth of 450 feet. Today the Coal Measures are known to extend not for 15, but for 25 miles. In a limited area of one square mile, known as the Disang-Borhat area, Simpson, in 1906, allowing 25 feet of workable coal, considered that $1\frac{1}{2}$ million tons could be profitably extracted from a total of 2,676,830 tons, pointing out at the same time that it is very probable the seams continue to be of economic value for many miles beyond the limit he was able to prospect. During 1949-50, T. Banerjee re-examined the area between the Dihing and Dikhu rivers and estimated the available reserves at 3,850,000 tons. Practically the whole of the coal, however, lies below water level. A small mine was opened at Hapjan in 1910, the coal being conveyed to Namrup by a tramway 4 miles in length, but it was not a profitable venture. The proprietors of the Bemolapur tea garden quarried the outcrops of two seams, measuring 6 and 4 feet in thickness, near their property for a short time. The Dilli colliery, which was taken over by its present owners in 1945, contains a number of distorted seams, aggregating a total thickness of 25 feet, near the Disang river. The coals from this mine contain: Moisture 5 to 10 per cent, Volatile Matter 36 to 42 per cent, Fixed Carbon 42 to 53 per cent, Ash 2 to 18 per cent. Their sulphur content is about 2.5 per cent.

Coal production from the Sibsagar district appears in the official returns as a total of 4,283 tons for the years 1917 to 1919, and then again from 1942 onwards: up to the end of 1950 a total of 193,859 tons had been raised, the output for 1950 being 26,944 tons.

Makum. The Namdang-Ledo, or Makum coalfield, lies to the east of Jaipur, and the Coal Measures occupy a narrow strip some 18 miles long and one mile broad. Mallet, in 1876, found the best outcrops in the $5\frac{1}{2}$ miles' stretch between the Namdang and Tirap streams. According to Evans (1932), thick coal seams with carbonaceous shales, shales and sandstones form the lower part of the Tikak Parbat Stage, while the workable seams are limited to a small part of the succession. The lowest or 'Thick' coal is often termed the '60-foot seam' and in many places it is divided

into three separate ones. Above this coal there are two comparatively thin seams, followed by the '20-foot' coal, which, in its turn, is also followed by several thinner seams. In some areas, parts of the 'Thick' coal are missing, and the 20-foot seam has been eroded over a large area near Baragolai. The average dip is high, but the outcrops, being often some hundreds of feet above the plains, permit of mining by means of adit levels. In 1900, G. E. Harris estimated that in the stretch of ground mentioned above there is a total of 90 millions of tons of coal above natural drainage level. According to Sir Cyril Fox, not less than a further 100 million tons exists between Ledo and Tipong, while 'taking the whole area involved from the longitude of Makum to the hairpin bend of the Tirap, say 50 square miles, the quantity of coal within a depth of 2,000 feet must be of the order of 1,000 million tons'.

Mining commenced in 1881 when collieries were opened at Ledo and Tikak and a little later at Namdang. A metre-gauge railway, 77 miles in length, was made to the fields from the Brahmaputra valley near Dibrugarh, and more collieries followed later, at Baragolai (in the Thick Seam of Makum), at Lakhpāni (in the Lakhpāni seam) and at Tipongpani (in the Makum Thick and 20-foot Seams). The coal is of excellent quality, a valuable gas-producing material which also furnishes a hard, porous, low ash coke; its only defect is its large sulphur content. A recent analysis of a dried sample showed: Volatile Matter 44.38 per cent, Fixed Carbon 52.92 per cent, Ash 2.70 per cent. Moisture in original sample 2.06 per cent, Sulphur 2.89 per cent. The average theoretical calorific value of ten samples of Makum coal, quoted by R. R. Simpson, is 7,447 calories, compared with the value of 6,526 calories calculated for thirty-one samples of Raniganj coal. Makum coal is consumed by railways, river steamers, tea factories, and rice and oil mills in Assam. In 1884, the output was 19,493 tons and by 1900 it had risen to 215,962 tons: for the next twenty years it fluctuated between 250 and 305 thousand tons per annum. The highest production was 307,414 tons in 1930, and in 1950, 303,584 tons, being 0.94 per cent of the total Indian output for that year, were raised. The total tonnage taken from the field between 1900 and 1950 was 13,125,970 tons.

Namchik. The discovery of coal in the Namchik valley, close to its junction with the Dehing river, and but 18 miles in a straight line from Ledo, by W. Griffith and H. Bigge, was announced by the latter to the Asiatic Society of Bengal in 1837. Later, the seams were described by Medlicott in 1865 and examined by Sir Edwin Pascoe in 1911. He reported five groups of seams within 360 feet of strata: their total thickness is 60 feet, of which only 5 or 6 feet are of poor quality; the best seam is $21\frac{1}{2}$ feet thick but it contains 3 thin clay bands. The average analysis of the coal is:

Volatile Matter 44·4 per cent, Fixed Carbon 52·9 per cent, Ash 2·7 per cent. The Coal Measures are an extension of those of the Makum field and they have also been traced further east still in the Namphuk valley, where 600 million tons of workable coal are said to be available, and on to the slopes of the Miao Bum range, though here they appear to be thinning out. All these localities lie beyond the eastern border of the Lakhimpur district and in the Sadiya Frontier Tract.

ANALYSES OF ASSAMESE COALS

LOCALITY	MOISTURE	VOLATILE MATTER	FIXED CARBON	ASH	REMARKS
Garohills ..	5·64	40·90	50·72	2·74	average of 4 samples, 2·72% sulphur
Cherrapunji ..	4·14	50·38	42·71	2·77	....
Nazira ..	4·35	48·00	45·70	1·95	Borjan colliery
Namdang ..	2·25	42·27	54·27	1·21	Makum colliery
Ledo ..	1·80	40·15	55·59	2·46	sample of 49 feet of coal
Tikak ..	2·09	37·25	58·99	1·67	sample of 47 feet of coal

TERTIARY COALFIELDS OF KASHMIR

The next Tertiary coalfields to be described lie in the Jammu Province of Kashmir, but it is necessary to mention the recent discovery of an intermediate occurrence near the base of Mahabharat Lekh, in the Sallyana district of west Nepal, where G. N. Dutt has found coal seams of Eocene age up to 8 feet in thickness and with about 12 per cent of moisture, 21 per cent of volatile matter, 31 per cent of fixed carbon and 36 per cent of ash.

The Coal Measures of Jammu occur on the flanks of elongated domes, strung out roughly east and west, over a distance of 40 miles across the hills some 20 miles north of Jammu city. There are six of these structures: the large Riasi dome, bisected by the Chenab river from north to south, and its isolated representative of Dandli; the smaller domes of Mahogala, Metka and Kalakot, and finally the subsidiary northern group of Dhanswal-Sawalkot, found in 1924. Visited by Medlicott in 1859, various reports have been written on them including those by La Touche (1888) and Simpson (1904). Middlemiss, in 1929, investigated in fuller detail the three smaller domes and noted briefly on the Dhanswal-Sawalkot, Chakar and Chinkah fields, the two latter forming part of the Riasi dome, west of the Chenab. The Coal Measures underlie the Nummulitic limestone and are divided into an Upper Series, probably of Lower Eocene age, about 120 feet thick, and an irregular Lower Series, 4 to 24 feet thick, also known as the Bauxitic Series as shown in the following Table.

COAL-BEARING SEQUENCE OF KASHMIR

NIMADRIC BEDS (MURREES & SIWALIKS)		Miocene and younger.	
		unconformity	
PROBABLY LOWER EOCENE	NUMMULITIC LIMESTONES & SHALES .. .. .	..	About 400 feet (Eocene).
	UPPER COAL MEASURES .. .. .	..	Carbonaceous shales with coal seams and ironstone bands. Total thickness about 120 feet.
	BAUXITIC SERIES WITH LOWER COAL MEASURES		Bauxite, bauxitic clays and kaolin with local ironstone and coal in thick seams at certain places. Thickness 4 to over 24 feet.
BRECCIA .. .. .	.. .. .	..	Chert fragments in calcareous or siliceous cement; 20 to 30 feet. Age unknown.
GREAT (RIASI) LIMESTONE .. .. .	.. .. .	..	Massive grey limestone. Probably Permian.

NOTE :—On the flanks of the domes the coal-bearing Eocene rocks are overlain by the sandstones of the Murree Series. In their inner parts the underlying Great (Riasi) Limestones crop out.

In the Dandli field, described by C. M. P. Wright in 1905 and by D. N. Wadia, in part, in 1928, which crosses into Poonch, there are two or three inconstant, lenticular seams, from 6 to 36 inches thick, of extremely crushed coal, which in Wright's opinion offer no inducement to exploitation. The only workable portion of the Ladda-Sanganmarg field of the Riasi dome, according to Simpson, lies between Ladda and the Anji valley, east of the Chenab, where a seam, averaging about 31 inches in thickness, probably contains about $1\frac{3}{4}$ million tons of workable coal and possibly $3\frac{1}{2}$ million tons above free drainage level. In the years 1902-4, 2,407 tons were taken from this Ladda field.

In the areas west of the Chenab, outcrops of a seam of workable thickness occur at several places between the river and Chakar, near the western end of the Riasi dome, and over a distance of some ten miles. Middlemiss thought that the region around Chinkah, near the river itself, should yield 6 million tons. The Upper Measures of the Chakar field have two seams, each about 5 feet in thickness, with a reserve of about 9 million tons.

Five miles west of the Chakar field lies that of Mahogala where the seams of the Lower Measures are sporadic and poor, but the Upper Measures, especially to the north and east, have two main seams of low volatile coal of excellent quality, though it is soft and friable. The two seams total about 12 feet in thickness and 4 million tons of coal are regarded as 'reasonably in sight' in them.

The Metka field, one mile west of Mahogala, has three separate seams in the Upper Measures with a total, average thickness of 5 feet, from which 5 million tons of mainly friable, semi-anthracitic coal may be obtainable.

Kalakot is the most westerly member of the main, southern group, situated $1\frac{1}{2}$ miles west of the Metka field. Its Lower Measures contain a seam of good-quality, hard, semi-bituminous coal, varying up to 17 feet in thickness, with estimated minimum reserves of 1 million tons. An upper seam in the Upper Measures is from 4 to 7 feet thick and should yield about 6 million tons of second-class fuel, for though a low volatile, bituminous to semi-bituminous type, it is relatively high in ash. A thin, 2- to $2\frac{1}{2}$ -foot seam occurs, still in the Upper Measures, though 40 feet below the former one. Both it and another middle seam are said to contain a further 2 million tons of very good coal, perhaps all of which, however, will require briquetting before being marketed, if it ever comes to be mined.

The outlying Dhanswal-Sawalkot field stretches to the east-south-east from Dhanswal to Lodhra, a distance of about 12 miles, and in it the main seam, up to 7 feet in thickness, rests on the Bauxitic Series. Its coal is greatly crushed and powdery, of an anthracitic character, with only about 10 per cent of volatile matter and a high ash content. Its possible reserves have been given as 9 million tons. About 40 feet above this seam there is another thinner one. In calculating the reserves of the Kashmir fields, an arbitrary limiting depth of 1,000 feet has been taken, but there is no apparent geological reason why the seams should not extend to greater depths than this.

About 1945, the Mining Department of Kashmir announced the discovery of a seam of good coal, 4 feet thick, at Khuiratta, some 18 miles to the west of the Kalakot field, and of another steeply dipping seam of similar quality, 10 feet thick, at Jangalgali, about 42 miles by road, north-north-east of Jammu. Departmental mining by underground methods commenced at Kalakot and Jangalgali, both of which are in the Riasi district, about 1945, and open-cast quarrying of outcrop material at Dandli, in the Nurpur district, in 1943. While the coal from Kalakot is hard and lumpy, that from Dandli is a semi-anthracitic powder which is used in brick kilns. The coal from Jangalgali too is powdery, but it can, however, be coked. The total output of coal recorded from Kashmir between 1939 and 1949 was 35,827 tons.

The Eocene coals of India and Pakistan are largely of a lignitic character, but in Kashmir as well as certain other Himalayan areas, higher rank coals occur, the change having been brought about by the pressures developed during the earth movements which accompanied the growth of the range, mainly during late Tertiary times. Thus it comes about that the Jammu coal has a semi-bituminous and anthracitic character while most of it is very friable with a marked foliated structure. It burns with little flame or smoke, and when washed and briquetted forms a fairly good steam coal. Some varieties coke strongly and most appear to contain a high percentage of sulphur.

ANALYSES OF KASHMIR COALS

LOCALITY	MOISTURE	VOLATILE MATTER	FIXED CARBON	ASH	REMARKS
Ladda ..	1.03	12.42	69.74	16.81	average of 6 samples
Metka ..	1.96	12.60	71.54	13.90	average of 10 samples
Mahogala ..	3.78	14.76	71.60	9.86	average of 6 samples
Kalakot ..	0.63	12.25	78.12	9.00	Lower Measures
" ..	4.62	14.54	69.44	11.40	Upper Measures

TERTIARY COALFIELDS OF THE WEST PUNJAB, PAKISTAN

The events which led to the formation of coal seams in southern Kashmir during early Eocene times were not confined to that region, but affected a wider part of north-western India including the West Punjab. The retreat of the sea towards the end of the Mesozoic period and the formation of a land surface, typified in Jammu by the Bauxitic Series and the coal seams which follow it, has its counterpart in the Lower Eocene (Ranikot) laterite and the associated Makerwal coal seam of the trans-Indus Salt Range beyond Kalabagh.

After its formation there were further encroachments of the sea, marked by the foraminiferal limestones, marls, shales and subordinate sandstones which follow it, but local estuarine and marshy conditions disturbed this particular marine phase during late Ranikot and succeeding Laki times. It was during a marine recession of the Upper Ranikot that the Dandot seam was formed over what is now the eastern Salt Range and parts of the Kala Chitta area, while during the ensuing Laki period several thin seams had their origin in parts of Baluchistan and Sind.

The Coal Measures of the West Punjab in Pakistan then are found at two distinct geological horizons of Lower and of Upper Ranikot age, though both are not productive in the same fields. The coals themselves are lignitic in character and either non- or poorly caking; sometimes banded and bright, liable to marked variation of composition from place to place, and often in a single seam, and relatively high both in moisture and sulphur. The seams crop out mainly in the scarps overlooking the Jhelum plain in the eastern Salt Range and that of the Indus, in the Mianwali district, in its western extension. Early accounts of the Punjab Salt Range coal were given by A. Fleming between 1848 and 1853, while a later list made by T. Oldham, the first Director of the Geological Survey of India, mentions thirteen localities, many of which, however, have no economic significance.

Eastern Salt Range. In the middle part of the Salt Range scarp, the Dandot seam is found associated with shales lying between limestones of Ranikot and Laki ages, respectively; it is thus somewhat younger than the Makerwal seam of the trans-Indus range described below. The Dandot seam is fairly constant eastwards as far as the Bhaganwala area but westwards it is shaly and is not mined. It continues northwards beneath the underlying Laki limestones and shales of the plateau, and being horizontal, or only gently inclined, lies within depths of 250 and 450 feet. As a result of the rugged topography and the intersection of the plateau by deep gorges, various separate areas have to be mentioned though only one seam is concerned and the workable area, as far as is known, is confined to a distance of 3 to 5 miles from the scarp face, though the Coal Measures come to the surface again 12 to 15 miles to the north on the slopes of the Diljabba range.

Bhaganwala Area. This includes the small plateau 8 square miles in extent, around Ara, in the eastern part of the range, and originally the outcrop of the seam could be traced for about a mile. In 1893, La Touche estimated a reserve of 88,000 tons of proved and available coal, in a seam which varied from practically nothing up to a maximum of 7 feet in thickness. Between 1877 and 1893 about 2,000 tons of outcrop coal were removed, and in the latter year the North-Western Railway Co. commenced mining, connecting its pits with the Sind-Sagar line at Haranpur, about 1896. The maximum production was 13,145 tons, in 1897, but operations ceased in 1900 owing to the poor quality of the coal.

Dandot Area. From Bhaganwala the Coal Measures continue cropping out to the west-south-westwards around the scarp, and the next area of mining activity includes the tracts around Dandot, Pidh and Manihala, where the seam varies from 2 to 4 feet in thickness. It was mined beneath the Laki limestones both at Dandot and at Pidh, 3 miles to the north-east, by the railway company between 1884 and 1911, when the collieries were sold to a private firm. Various small concerns continue to work in this area, and it has been proposed that the existing tramway system, which terminates on the Pidh platform, should be extended and linked with the upper terminus of a new overhead ropeway to convey the coal down the scarp to Dandot railway station. The total output from 1900 to 1946 was 2,283,219 tons; the record annual output during that period was 81,218 tons in 1899, and the production for 1946 was 76,852 tons.

Chittidand Area. On the Chittidand plateau, just to the west of Makrach, about 4 miles west of Dandot, as the crow flies, the Eocene limestones form another basin several square miles in extent. The coal seam below them again varies up to about 4 feet in

thickness. The output from the drifts here is moved by tramway to the railway at Golpur, and it is counted as part of the Dandot production.

Dhak-Katha Area. From the Chittidand plateau the Coal Measures again continue westward, cropping out along the scarp slopes past Sardahi and Nurpur, to the Dhak-Katha area of the Sargodha district. Numerous small mines have been at work for many years north-north-west of Katha, as at Tejuwala near the crest of the scarp, and at Jhakarkot, $3\frac{1}{2}$ miles further south-west, where a variable seam averages about 3 feet in thickness. They are connected by a tramway with the railway at Dhak station to the south. From 1905, when separate statistics commenced, to 1946, a total of 268,772 tons had been won, the annual outputs steadily increasing to a maximum of 12,280 tons in 1946.

A firm of consulting mining engineers, engaged by the Government of West Pakistan in 1949, has estimated the workable reserves of coal in the Salt Range of the West Punjab as follows:

WORKABLE RESERVES OF SALT RANGE COAL

AREA	RESERVES (tons)	AREA	RESERVES (tons)
Dhak-Katha	5,250,000	Diljabba	4,000,000
Pidh-Dandot	10,500,000	Dalwal	3,450,000
Rakh Drengan & Rakh Dewan	13,800,000	Chittidand	3,000,000
Rakh Manihala	18,500,000	Nurpur	3,700,000
North & west of Ara ..	7,500,000	TOTAL ..	69,700,000

NOTE.—The successful recovery of these reserves is dependent on the provision of capital, the introduction of modern mining methods and the construction of proper surface transport facilities.

Trans-Indus Ranges. The thin coal and coaly shale bands which occur in the Jurassic rocks, north of Kalabagh on the west bank of the Indus, and also above Kutch a few miles further north, in the Mianwali district, are of little economic interest and workable coal seams are confined to the Lower Eocene. The general direction of the Salt Range on this side of the Indus, where it is known under a variety of names, is at first northwards and then westwards from Kalabagh to beyond Chapri and later it turns southwards to the Kurram river, the Coal Measures cropping out in the scarps overlooking the alluvial plain of Isa Khel. The Dandot seam of the eastern Salt Range lies above the Ranikot limestones, but the Makerwal seam of the trans-Indus section lies

in the basal Eocene sandstone below them. The horizon of the Dandot seam itself, both here and in the western half of the cis-Indus range, is merely represented by carbonaceous shale. The Makerwal seam is on the whole similar to the Dandot one, though in places of somewhat superior quality. It varies greatly in thickness, being entirely absent in some parts and usually up to 3 feet thick, but in the south of the Makerwal area it is said locally to attain a thickness of 12 feet, including a shaly parting about its middle. The greater part of the outcrop of the Coal Measures lies within the Isa Khel *tahsil* of the Mianwali district of the West Punjab, but around and south-west of Chapri, the beds dip northwards and westwards beneath the limestones of the Kohat district, in the North-West Frontier Province. It is again necessary to consider separate areas as follows:

Kalabagh-Chichali Area. A thin seam, 2 to 3 feet in thickness, occurs at the base of the Eocene near the top of the scarp north of Kutch, and it has been opened up by a few small workings. Eocene rocks continue for about 7 miles along the strike to the south-west to the Chichali pass, where a similar thin seam is exposed on the eastern slopes.

Kurd-Malla Khel Area. Commencing 4 or 5 miles west of the Chichali Pass, this area embraces the whole sweep of the Maidan-Surghan part of the range, as it changes its direction from north-east to south, a distance in a straight line of 13 miles. Several small workings have proved the seam to vary rapidly up to a few feet in thickness, though in some localities it has not been found.

Makerwal Area. This area lies 4 miles directly south of Malla Khel, and from it both to the west and north-west of the town of Sultan Khel, more than half of the Punjab's production of coal has been won in recent years. The seam underlies the massive sandstones of the Lower Ranikot Stage and locally attains a thickness of 10 feet, though it usually varies between 4 and 8 feet. R. R. Simpson's prediction, in 1904, that successful mines might be established here has been fulfilled. The production of 765 tons in 1907 rose to 7,000 tons in 1912, to over 30,000 tons in 1932 and to a record of 117,000 tons in 1939. The total output from the commencement to the end of 1946 was 1,519,115 tons. The area between Makerwal and Malla Khel has been developed more recently. The mines are served by a metre-gauge track, about 30 miles long, from Mari station on the Indus. The Makerwal collieries, covering a lease of 1,691 acres, were taken over by the Punjab Government in 1948 and later by the Central Government of Pakistan. The workable reserves of the trans-Indus fields are estimated at 18,870,000 tons, of which 6,270,000 tons are in the Makerwal area: proved and readily available reserves above water

level amount to 1,100,000 tons. Just south of Makerwal colliery the Coal Measures disappear beneath alluvium. The West Punjab and Baluchistan between them account for practically the whole of the coal production of Pakistan and statistics published by its Department of Mineral Concessions, in 1950, give the total output for the fifty years ending 1950 as 7,059,458 tons, of which 4,689,857 tons, or 66.4 per cent, came from the West Punjab.

COALFIELDS OF BALUCHISTAN

Thin coal seams of Eocene age occur in various parts of Baluchistan though easily accessible areas containing workable seams are not numerous. They include the Khost-Sharigh-Harnai group, the Sor Range and Digari fields and the Mach area. The seams occur within the Ghazij Shale Stage of Laki age and are thus at a higher horizon within the Eocene sequence than those of the Punjab. They are associated with a great thickness of gypsiferous, olive-green shales and sandstones, themselves overlain and underlain by Eocene limestones: above the latter follow the shales, sandstones and clays of the higher Tertiary, Gaj and Manchhar Stages.

Khost-Sharigh-Harnai Belt. The Coal Measures of this belt, which is situated some 30 to 40 miles east of Quetta, and about 4,000 feet above sea level, extend from beyond Khost in the north-west, through Sharigh and Nakus, to Harnai in the south-east, a distance of 25 or 30 miles along the general strike of the strata. They dip at high angles to the south-west and are approachable from the Sibi-Zardalu section of the North-Western Railway, which runs more or less parallel to them. A large number of thin coal seams and bands of coaly shale occur but many of them are only a few inches thick. In the Khost-Sharigh section thin seams of $1\frac{1}{2}$ to 2, 2 to 3 and $4\frac{1}{2}$ feet thick, respectively, have been worked. The Sharigh portion of the belt, according to S. T. Ali and N. M. Khan, who examined it in 1948, has a lateral extension of 6 miles. In the Nakus section, farther south-east, a seam, $1\frac{1}{2}$ to 2 feet in thickness, has been proved over a distance of $1\frac{1}{2}$ miles, while in the Harnai section there is a $2\frac{1}{2}$ to 3-foot seam which has been followed for more than 4 miles. M. Haque, of the Geological Survey of Pakistan, mapped the Harnai and Nakus areas of the Sibi district in 1948, and discovered a new $2\frac{1}{2}$ to 3-foot seam, traceable for about 6 miles. The consulting engineers to the Pakistan Government estimate the workable reserves of the Khost-Sharigh belt at 39,900,000 tons. Collieries were opened by the North-Western Railway Co. in 1877 at Khost; at Sharigh in 1894 and at Harnai in 1910, but owing to disturbed ground, variations in the seams themselves and the liability of the coal to spontaneous combustion, they were later abandoned. Owing to its friability much of the

Khost coal was briquetted before use. Today there are many small, separate, producing units, working the outcrop coal at shallow depths by primitive, hand-to-mouth methods. In 1900 the output was 17,664 tons and it rose to a maximum of 45,585 tons in 1913, gradually falling away to 17,085 tons in 1925. The collieries were closed about this time, though a few thousand tons continued to come annually from the region. A pronounced revival occurred in 1942, with an output of 26,234 tons. The production in 1946 was 23,075 tons and from 1900 to the end of that year, a total of 1,008,240 tons had been obtained.

Sor Range. Over a distance of 7 miles along the scarp of the Sor Range, 10 to 15 miles east of Quetta, there are a number of small mines exploiting two seams from their outcrops: the upper of the two is $2\frac{1}{2}$ feet thick and the lower one $4\frac{1}{2}$ to 5 feet thick, though it is not present everywhere. The intervening shales vary from a few feet to about 100 feet in thickness and the dip is from 40° to 50° . Here, as elsewhere, the workings follow the dip of the seams and their extent is usually limited by the underground water level. A metalled road joins Spin Karez with Quetta and a fair-weather road, maintained by the lessees themselves, connects the various workings with it. The coal is usually slack and powdery; the ash content is often low, but there is an appreciable amount of sulphur, rising in some cases to as much as 4 per cent.

Digari. The Digari field is 6 miles south of the Sor Range, in the Quetta-Pishin district and the Kalat State, about 18 miles from Spezand Junction. When R. D. Oldham visited the field in 1890, the mines had been worked fitfully for many years and the workings were at that time strewn along more than a mile of outcrop. M. Haque and M. I. Ahmed investigated the field in 1941-2 and reported the presence of three or four seams at Digari, of which only two are workable: a lower one, 5 feet thick, and an upper one, $2\frac{1}{2}$ feet thick, separated by shales and sandstones up to 40 feet in thickness. Both seams are pyritic with a sulphur content ranging between 1.8 and 4.1 per cent; the ash varies from 4.8 to 7.1 per cent. About a mile north of Digari, two seams are mined at Sherin Ab; separated by 50 to 100 feet of sandstones, they are $2\frac{1}{2}$ feet thick in the case of the upper one, and 5 feet thick in the lower one, although this also contains some shaley bands. The coal of the upper seam contains 14.8 per cent of ash and 1.9 per cent of sulphur, and, like most Digari coal, consists of lump and slack in roughly equal proportions. The total probable reserves of workable coal are given as 17,990,000 tons in the Sor Range and 3,990,000 tons in the Digari-Shirin Ab area.

Mach. The existence of coal at Mach, in the Bolan Pass, was noted by Hutton in 1846 and the occurrences are within a few

miles of the main railway line to Quetta. There are a number of thin seams up to $3\frac{1}{2}$ feet thick, but only three or four of them are workable. As the whole of this area has been subjected to great tectonic disturbance, the Coal Measures in the soft Ghazij Shales, mostly unprotected by harder, overlying beds, have suffered severe folding and faulting, so that mining becomes unusually complicated and the small workings generally end within a few hundred feet of the outcrops. The coal is friable with sulphur contents up to 6.5 per cent. Assuming a total length of 3 miles and an aggregate thickness of 4 feet, a quarter of a million tons should be obtainable within a depth of 100 feet. The mining consultants to the Government of Pakistan, however, compute the total, workable reserves as 15,050,000 tons, though to obtain this, capital, as well as modern mining methods and machines, will be necessary. Official coal statistics as published do not separate the small production of the many individual mines, often operated by petty lessees and small sub-contractors, in the Sor Range, Mach and Kalat areas. At the commencement of the present century, the aggregate total output was about 5,600 tons per annum and with minor fluctuations it increased to over 13,000 tons in the next twenty years. The largest recorded output of those days was in 1922, with its 26,269 tons, and thereafter it varied widely between 5,000 and 17,000 tons until the forties. The second world war and subsequent events greatly stimulated the industry, production jumping from $10\frac{1}{2}$ thousand tons in 1942 to 40,000 in 1943, passing 100,000 tons in 1944, and reaching 173,563 tons in 1946, giving a grand total of 898,831 tons for the period 1900 to 1946, inclusive. Since that time output has continued to rise, particularly in the coalfields of Baluchistan as a whole.

The total output of the West Punjab and Baluchistan for the 50 years 1901 to 1950, was, as already stated, 7,059,458 tons, and to this total Baluchistan contributed 33.6 per cent and the West Punjab 66.4 per cent, but these figures give no indication of a marked change which has taken place. In the earlier years the output of the West Punjab generally greatly exceeded that of Baluchistan, but since 1945 Baluchistan production has approached, and in some years passed, that of the West Punjab. Thus, for the five years ending 1950, while the average annual production from the West Punjab was 176,890 tons, that from Baluchistan was 171,780 tons, compared with 151,604 tons and 62,201 tons, respectively, for the previous quinquennium, ending 1945. These are small figures as coal tonnages are reckoned but they are of some economic significance in a region where fuel is so scarce, the distances to the important Indian fields so great, and the local demand so much in excess of internal supplies. The Department of Mineral Concessions of the Government of Pakistan estimated in 1950 that the demand for coal of all types was about $3\frac{1}{2}$ million tons per annum at that time.

COALFIELDS OF SIND

Jhimpir. A thin, lenticular seam of lignitic coal, 9 to 30 inches in thickness, occurs amongst the sandstones and shales forming the uppermost division of the Lower Eocene, Ranikot Series, about Jhimpir, Meting and other places in the Karachi district of Sind, about 80 miles north-east of Karachi itself. It is unusually high in moisture, contains 6 to 8 per cent of ash and is liable to spontaneous combustion. The seam, with a low and uniform dip, lies 50 to 70 feet below a series of low hills and is mined from short adits over an outcrop length of 12 miles. The Jhimpir portion of the field is about 6 miles from the railway station of the same name. The consultants of the Pakistan Government have recommended the drilling of the Jhimpir field as a matter of primary importance to prove its extent and resources. Production commenced with 6,245 tons in 1944 and 73,984 tons had been won by the end of 1950.

OTHER COAL OCCURRENCES IN PAKISTAN

The Coal Measures of the Mianwali district of the West Punjab continue down dip into the Kohat district of the North-West Frontier Province and are found on the crest of the Surghar range, just under which the outcrops are worked. The seam also crops

ANALYSES OF COALS OF THE WEST PUNJAB, PAKISTAN

LOCALITY	MOISTURE	VOLATILE MATTER	FIXED CARBON	ASH	CALORIFIC VALUE	REMARKS
Dandot ..	5.37	43.65	38.04	12.44	..	....
Pidh ..	4.44	40.38	38.70	16.48	..	....
Rakh						
Drengan ..	5.3	38.8	41.6	14.3	11,100	....
Chittidand ..	5.1	40.8	38.1	16.0	11,100	....
Katha Mine ..	5.2	37.7	44.8	12.3	10,900	....
Makerwal ..	2.80	42.34	36.94	17.92	..	6.35% sulphur
" ..	3.04	43.43	44.29	9.24	..	5.90% sulphur

ANALYSES OF COALS FROM BALUCHISTAN, PAKISTAN

LOCALITY	MOISTURE	VOLATILE MATTER	FIXED CARBON	ASH	CALORIFIC VALUE	REMARKS
Khost ..	2.29	41.51	46.52	9.68	..	....
Sharigh ..	6.80	40.80	47.60	4.80	..	Picked sample
Nakus ..	2.4	44.5	43.8	9.3	12,400	5.5% sulphur
Shirin Ab ..	11.9	38.8	43.1	6.2	10,700	2.1% sulphur
Mach ..	10.9	33.1	41.0	15.0	..	....

NOTE.—Coals of the West Punjab and Baluchistan are either non-caking or poorly caking.

In the case of coals dispatched from the mines, the ash content is often appreciably higher than that shown by the above analyses, owing to lack of care in removing shale bands.

out in the Baroch gorge of Kohat where it is 2 feet and 10 inches in thickness.

The coal of the Cherat Hills, Nowshera, Peshawar district, was investigated by N. M. Khan and J. M. Master in 1948, and though originally a thin seam it is now broken up into lenses of small dimensions through the action of earth movements. Their discontinuity and thinness together with the crushed condition of the surrounding ground do not warrant mining operations.

An irregular seam of coal, greatly crushed and sheared, crops out among shales which underlie Nummulitic limestone, in the Dore valley, east of Abbottabad, in Hazara. It varies greatly in thickness, from nothing up to 17 feet; most of it is of very poor quality with a high ash content. Small quantities have been mined in the past for local brick-burning and lime kilns, but attempts to exploit it on a larger scale have not been profitable.

COALFIELDS OF BURMA

GOALS OF JURASSIC AGE

Panlaung Valley and Loian. Coal seams of Jurassic age occur in the Panlaung valley, on the edge of the Southern Shan plateau, and some of the exposures were described by E. J. Jones in 1887. They were examined in 1932 by V. P. Sondhi, who found that the Coal Measures build the Legaung ridge for a distance of 8 miles, and stretch in a band, 3 to 3½ miles wide, across the Toklet valley and through the Wetpyuye forest into the Panlaung valley proper, a distance of 13 miles. The coal is scattered in pockets, streaks and lenticles and at only one locality, 1½ miles south of Legaung, is it considered worth further examination.

In the southerly extension of the same Coal Measures, between Myinka and Konhla, the best known locality is the Loian coalfield near Kalaw, but it is a very disturbed region in which the Coal Measures themselves are tucked into the axes of reversed folds in older limestones, or faulted down into them. Extensive underground exploration was carried on here about 1922 but without commercial success, the seams proving exceedingly irregular, crushed and broken. Most of the Shan Jurassic coals are more or less powdery and could not be marketed without briquetting, though some of them form a good, hard coke.

Henzada. The Jurassic coal seams of the Henzada district were described by Murray Stuart in 1910. Perhaps the best occurrence is that near Kywezin, where a seam 8 feet thick is exposed, but the strata are greatly contorted and the coal so crushed that its volatile contents have been diminished while its fixed carbon percentage is high. Attempts at mining here have not been successful and large-scale tests of the coal have been disappointing. There are other seams of minor importance at Hlemauk and Posugyi.

THE MINERAL FUELS
ANALYSES OF BURMESE JURASSIC COALS

LOCALITY	MOISTURE	VOLATILE MATTER	FIXED CARBON	ASH	REMARKS
Loian ..	0.7	26.4	60.2	12.7	mean of 7 samples
Kywezin ..	1.68	17.59	74.44	6.29	" " 3 "

COALS OF TERTIARY AGE

Tertiary coal seams are known in several districts of Burma. Thin, crushed and shaly seams were examined in 1896 by Sir Henry Hayden at Mithwe in Bhamo, while in the adjoining district of Katha, F. Noetling, in 1893, had already reported the presence of several seams, including one of fair quality, 4 to 5 feet thick, at Yuyinbyat, near Pinlebu. Near Kyaukset, in Minbu district, there is stated to be a seam 4 feet 7 inches thick, while from the Yaw river valley in Pakokku, G. de P. Cotter and Rao Bahadur Setu Rama Rao, in 1914, described seams varying from 5 to 6 feet in thickness but with numerous shaly partings and of low calorific value, near Letpanhla and Tazu. The irregular seam of Lime Hill, near Thayetmyo, and the thin ones of Cap Island, Cheduba, and Ramree, in Arakan, are probably worthless.

Kabwet. T. Oldham, in 1855, visited three coal outcrops a few miles west of Kabwet in the Shwebo district, and they were certainly mined by the Burmese before the British occupation of Upper Burma, i.e. before 1885. The coal-bearing area lies between the Kabwet bend of the Irrawaddy and its tributary the Man Chaung, and mining was confined to a single seam about 6 feet thick. A company carried on operations here at intervals between 1891 and 1904, when the workable coal is said to have been exhausted. The annual output varied from 10,000 to 15,000 tons, though in 1896 23,000 tons were extracted.

Upper Chindwin. The most extensive coalfields of Burma proper lie in a very isolated part of the valley of the Upper Chindwin and probably for this reason have remained undeveloped. The Coal Measures are of Eocene age and they occupy the valleys of the Nantahin, Peluswa, Maku and Telong streams, to the north of the Kale river, a tributary of the Chindwin, for a distance of 55 or 60 miles. According to Noetling (1889), seams of 2 feet and under are the general rule, but thicknesses up to 12 feet occur. In the Nantahin-Peluswa tract, with an area of 25 square miles, a total thickness of 48 feet of coal was considered to be available, and on the assumption that this could be worked to an incline depth of

1,000 feet from the outcrop, Noetling estimated that there are 210 million tons of workable coal in this limited portion of the Upper Chindwin field.

ANALYSES OF BURMESE TERTIARY COALS

LOCALITY	MOISTURE	VOLATILE MATTER	FIXED CARBON	ASH	REMARKS
Yaw River ..	18.73	34.15	35.86	11.26	mean of 22 assays
Kabwet (Shwebo) ..	12.27	37.45	38.97	11.31	" " 2 "
Chindwin ..	10.14	34.59	49.95	5.32	" " 13 "

LIGNITE

The lignites, or brown coals, represent an early stage in the transformation of plant tissues into the black coals, and as in most instances the Eocene coals of India, Pakistan and Burma have not matured beyond the lignitic stage, it would not be incorrect to classify such examples here. But in some cases their composition has been greatly changed through the influence of the intense tectonic pressures to which they have been subjected, as in the semi-anthracitic coals of southern Kashmir, and it becomes difficult to draw a strict line of division. Thus the grouping adopted here is purely an arbitrary one and under the term 'lignite' are included the fuels of Miocene or younger age, formed under shallow-water, estuarine conditions in some parts of southern India; the resinous, woody coal of Eocene age, occurring in Bikanir, Rajasthan; and others, found mainly in Kashmir and Burma, which were laid down for the most part in areas of more or less enclosed drainage, under lacustrine or fluvio-lacustrine conditions.

As a group such lignites are characterized by high moisture contents, volatile constituents ranging from about 30 to 50 per cent and fixed carbon under 50 per cent. They are light in weight, often dark brown in colour, of tough structure and sometimes displaying a wood-like, fibrous structure. They weather rapidly on exposure, splitting easily into thin layers, and readily fall into powder-defects which can be remedied by briquetting before their use as fuel.

LIGNITE FIELDS OF SOUTHERN INDIA

Cuddalore-Pondicherry Area, Madras. The occurrence of lignite under the coastal flats between Pondicherry and Cuddalore has been known since 1884, when W. King published an account of assays and trials of local lignite made for a French firm, who proposed to compress the material into briquettes for fuel, a venture which was not carried to a successful conclusion. The lignite had

been proved in three boreholes at the following localities: Bahur, 5 miles north-north-west of Cannanore; Aranganur, $2\frac{1}{2}$ miles north of Bahur, and Kanniyakovil, 3 miles north of Cannanore. The depth of the seam from the surface and its thickness were, at Bahur, 257½ feet and 35 feet; at Aranganur, 203 feet and 27 feet; at Kanniyakovil, 330 feet and 50 feet. From these depths it is calculated that the seam has a dip towards the south-south-east of 50 feet per mile. A second seam, $5\frac{1}{2}$ feet thick, was encountered in the borehole at Kanniyakovil at a depth of 330 feet. One of the better of several available analyses shows: Moisture 16.28 per cent, Volatile Matter 38.55 per cent, Fixed Carbon 37.72 per cent, Ash 7.45 per cent, Calorific Value 5,318 calories. Seven samples of the lignite analysed in Paris showed an average ash content of 8.35 per cent.

South Arcot. Lignite was found again about 1934 during boring operations for artesian water in the neighbourhood of Neyveli, near Vriddhachalam, South Arcot district, some 120 miles south of Madras. Three or four boreholes made by Messrs Binny & Co. (Madras), Ltd led to the further recognition of lignite of good quality, and systematic drilling by officers of the Geological Survey of India, under the direction of Dr M. S. Krishnan, were commenced in 1943 and completed in 1947, after proving a reserve of 320-400 million tons in an area of about 16-20 square miles in the taluks of Vriddhachalam and Cuddalore. Since 1947, the Government of Madras have been continuing the investigation and H. K. Ghose, their Mining Engineer, proved the extension of the field to a further 80-86 square miles, making a total of about 100 square miles with estimated reserves of 2,000 million tons. Since October 1951, the services of Paul Eyrich of the U.S. Bureau of Mines have been made available to the lignite investigation, as a mining consultant under Truman's Point-Four Programme.

About the middle of 1954, the Government of India, under the Colombo Plan, obtained the services of Messrs Powell Duffryn Technical Services Ltd, London. Their report, submitted in November 1954, is under examination by the Central and the State Governments. The experimental excavation for lignite which started with equipment obtained on loan from the Government of India in 1952 has gone to a depth of over 145 feet below ground and the results of the excavation will soon be available.

The field as at present defined is centred around Neyveli station on the Southern Railway, 27 miles from Cuddalore and 11 miles from Vriddhachalam, and though its northern and north-western limits are known, its extension to the south and south-east beyond the Vellar river has still to be proved. The area is occupied by Cuddalore Sandstones of Miocene age, alternations of soft, often waterlogged sandstones and grits with clays of various colours.

The country is practically flat with a very gentle seaward slope displaying occasional banks of lateritized sandstone. The lignite occurs as a regular seam, varying from 0 at the field boundary to 90 feet in thickness, with a low dip towards the east-south-east, and showing a tendency to thicken in this direction; it is nowhere found at a depth of less than 140 feet from the surface. When fresh the material is black and compact but it becomes dark brown and cracks on drying. The range of assay values from the drill cores was as follows:

Moisture (dry air)	..	..	11 to 15.5 per cent
Volatile Matter	..	..	40 to 53 per cent
Fixed Carbon	..	..	30 to 38 per cent
Ash	..	..	3 to 6 per cent
Phosphorus	..	..	traces
Sulphur	..	..	0.5 to 1.4 per cent
Calorific Value	..	..	9,000 to 9,900 British Thermal Units.

The moisture content *in situ* is approximately 45 to 50 per cent. The presence of strong water sands under artesian conditions caused considerable technical difficulties during boring operations and later when a shaft was sunk to the lignite seam. In both cases these difficulties were surmounted successfully, and during November, 1951, 120 tons had been raised for testing purposes. The thickness of the seam at the shaft bottom is stated to be 65 feet, and the depth of the shaft, including the seam itself, is 240 feet. No water under pressure was encountered above the lignite seam, but below it, under an intervening layer of clay varying in thickness between 0 and 35 feet, a sandstone carries an artesian aquifer under pressure.

The present experimental working lies about one mile north of Neyveli railway station and adjoins the site of the completed 10-foot shaft noted above. It covers an area of 600 × 600 feet, has a more or less tank-like form and is intended to expose an area of lignite covering 100 × 100 feet. This working, commenced on 5 March 1953, will afford data of the actual slope of the seam, its water contents and at the same time provide some idea of probable working costs. Such studies are necessary as a basis for the development of more extensive operations.

The overburden in this area will be about 180 feet, exposing a seam of lignite 60 feet in thickness. This gives an overburden to coal ratio of 3:1, which the advisory engineers consider well within the limits of economic recovery. The overburden itself carries two layers of refractory clays which will also be exploited. Any water accumulating during the course of the mining operations will be stored in 'tanks' which already exist in the neighbourhood, and directed from them for irrigation purposes.

The presence of lignite in the areas described in Pondicherry and South Arcot leads to the view that it may also be present in the Cuddalore Sandstones which occupy several scores of square

miles in the districts of Tiruchirapalli, Tanjore and Ramanathapuram, and that these areas should be systematically investigated for this purpose.

Lignite Deposits of the West Coast. The Cuddalore Sandstones of the East Coast have their counterparts on the West Coast, where they are known as the Warkalli (Varkala) Beds which are found not only at and around Varkala and Quilon, in Travancore, but also extend northwards into Malabar and South Kanara. As long ago as 1910, I. C. Chako and E. Massillamani, the State Geologists of Travancore at that time, estimated the presence of 276 million tons of lignite beneath an area of 41 square miles, near Varkala and other places. Moreover, lignite is known to occur near Bypore and Cannanore in Malabar and near Kasargod in South Kanara.

LIGNITE OF RAJASTHAN

Palana (Bikaner). A seam of dark brown, resinous, woody to peaty lignite was discovered at Palana, 13 miles south-west of Bikaner city, during well-sinking operations in 1896. It varies up to a total of about 20 feet in thickness, lies beneath foraminiferal limestones and is probably of Lower Eocene age. Mining commenced in 1898; railway connexion was established with the Jodhpur-Bikaner line and production commenced in 1900. Since that time it has continued without interruption, the fuel being mainly consumed on the railway after briquetting. Up to the end of 1950, a total of 1,509,318 tons had been won; the record output was 72,371 tons in 1948 and the average annual production for the five years ending 1949 was 60,187 tons. As mined, the lignite contains from 40 to 45 per cent of moisture, but a few days' exposure to the climate of the Rajasthan desert reduces this to 15 per cent or less. The seam is flat, and as the area is largely covered by desert sand, little is known about its possible extensions. Sir Cyril Fox mentions, however, that lignite has been proved at Madh, nearly 20 miles west of Palana, at a depth of 100 feet, while another seam has been found near Chaneri, 32 miles away, 180 feet below the surface. Thus it may well prove that the lignite resources of Bikaner are of considerable magnitude.

ANALYSES OF BIKANER LIGNITE

	MOISTURE	VOLATILE MATTER	FIXED CARBON	ASH
Dry Lignite	12.55	46.67	36.38	4.40
Briquette (1)	14.84	40.64	38.78	5.74
Briquette (2)	9.32	44.36	38.80	7.52

LIGNITE OF KASHMIR

Shaliganga and Handwara. The lignite fields in the Karewa formation of the Vale of Kashmir, which are of late Tertiary age, were described by C. S. Middlemiss in 1923. In the Raithan and Lanyalab basins of the Shaliganga area, a minimum amount of 4 million tons is available, while the Handwara area contains 32 million tons, in continuous seams from $2\frac{1}{2}$ to 6 or 8 feet thick, down to easily workable levels. The areas mentioned are 40 miles apart, but if, as seems probable, lignite also occurs in the higher, south-western, disconnected, Karewa basins, over the greater part of the Valley of Kashmir, the quantities would become very large indeed. It is a low-grade, rather impure fuel, earthy in appearance, of a dark brown to black colour and of a slabby structure, averaging some 15 per cent Moisture, 28 per cent Volatile Matter, 27 per cent Fixed Carbon and 30 per cent Ash. It can be burnt under favourable conditions in stoves and furnaces and may prove useful for distillation in the future. The Mining Department of the Kashmir and Jammu Government has marketed the raw lignite for local consumption since 1944, from workings at Nichoma and Raithan, in the Handwara and Badgam *tehsils* respectively. The total production from 1944 to 1946 was 6,403 tons.

LIGNITE OF EAST PAKISTAN

Sylhet and Mymensingh. Irregular, lenticular beds of lignite have been found along the banks of certain rivers and lakes, at about water level, in deltaic deposits of the Ganga and Brahmaputra rivers, over an area of about 170 square miles, in the Sylhet district of East Pakistan, extending northwards into the Mymensingh district. The average thickness which is visible above water, within a depth of 10 feet from the surface, is $2\frac{1}{2}$ feet.

LIGNITE OF BURMA

MERGUI DISTRICT

Theindaw-Kawmapiin. The Theindaw-Kawmapiin field of Mergui, the southernmost district of Lower Burma, in which shales, sandstones and conglomerates of late Tertiary age, deposited in old river valleys, corresponding generally with the existing courses of the more important streams, and its associated seams of lignite, have been the subject of numerous reports, extending over a period of almost one hundred years. The more important of these were summarized by A. M. Heron in 1919, together with the results of his own investigations. A number of seams, from 4 to 15 feet in thickness, are known, while their enclosing rocks cover an area of about 30 square miles. Practical tests of the fuel are said to have given good results, but until the field has been bored it is impossible to assess its potentialities. Similar lignites occur in the Lenya valley of the same district.

THE SHAN STATES

The lignite-bearing rocks of the Northern Shan States occupy a number of separate basins grouped around the mountain Loi Ling. They have originated from peaty deposits more or less *in situ* in lacustrine and fluvio-lacustrine deposits, the formation of which is still proceeding in the lakes which yet remain, both in the Southern Shan States and in the adjoining Chinese territory of Yunnan. Thus they range in age from late Pliocene to Recent times.

Lashio. The Lashio field, with an area of about 50 square miles, lies in the valley of the Nam Yau river, about 5 miles to the north of Lashio, the terminus of the Northern Shan States branch of the Burma Railways. It was surveyed by La Touche and Simpson in 1904-5 and they found several outcrops of brownish-black lignite, with a distinctly woody structure, varying from 3 to 25 feet in thickness. Tests of the outcrop material in a locomotive were not successful, but this is not surprising as the fuel had not been briquetted and the fire-box of the engine was of the normal type used for burning Bengal steam-raising coal.

Namma. The Namma field, with an area of 50 square miles, lies 11 miles south of the Lashio field and was investigated by Simpson in 1905. The principal seam of lustrous black lignite has been traced for about half a mile and varies from 7 to 17 feet in thickness. A portion of this field was explored by the Burma Corporation Ltd some 35 years ago, and two seams of 12 and 21 feet in thickness proved. According to E. L. Moldenke (1922), in the small area concerned there are 50 million tons of lignite in the lower seam and 30 millions in the upper one, but it has not yet been used on a commercial scale.

Mansang and Mansele. The Mansang and Mansele fields, 16 and 27 miles south and east of the Namma field respectively, are each about $13\frac{1}{2}$ square miles in extent. Surveyed by Simpson in 1905, they are known to contain numerous outcrops of lignite up to $4\frac{1}{2}$ feet in thickness.

ANALYSES OF BURMESE AND SHAN LATE TERTIARY LIGNITES

LOCALITY	MOISTURE	VOLATILE MATTER	FIXED CARBON	ASH	REMARKS
Kawmapyin (Burma).	13.87	35.74	43.75	6.64	mean of 2 samples
Lashio (Shan States)	20.65	35.63	31.08	12.64	" " 6 "
Namma " "	16.58	36.90	38.81	7.71	" " 5 "
Mansang " "	14.23	35.13	36.32	14.32	" " 6 "
Mansele " "	14.73	38.83	34.22	12.22	one sample

AVERAGE COMPOSITION OF INDIAN COALS

NON-CAKING COALS			COKING COALS	
BENGAL		CENTRAL INDIA	BIHAR	ASSAM
(a)			(b)	
%		%	%	%
Moisture	3 to 10	4 to 15	1 to 2	1 to 3
Ash	10 to 25	10 to 25	10 to 30	2 to 10
Sulphur	0.4 to 1.0	0.5 to 2.0	0.4 to 1.0	2 to 6
Volatiles	35 to 45	33 to 40	20 to 35	45 to 50
Fixed Carbon	55 to 65	60 to 67	65 to 80	50 to 55
Carbon	78 to 84	78 to 84	86 to 91	80
Hydrogen	5 to 6	4.5 to 5.5	4.5 to 5.5	5.0
Nitrogen	2.0	2.0	2.0	1.0
Sulphur	1.0	1.0	1.0	3.0
Oxygen	7 to 13	8 to 14	2 to 6	10
Calorific Value	14,000 to 15,000	13,500 to 14,700	15,400 to 15,800	14,500

(a) Represented mainly by coals of the Raniganj Measures.

(b) Mainly Jharia and Bokaro Coals but includes some from the Laikdih Series of the Raniganj Field.

Figures for moisture, ash and sulphur are based on samples 'as received'.

The remaining figures are based on a Unit Coal Basis, that is to say on coal free from moisture and mineral matter.

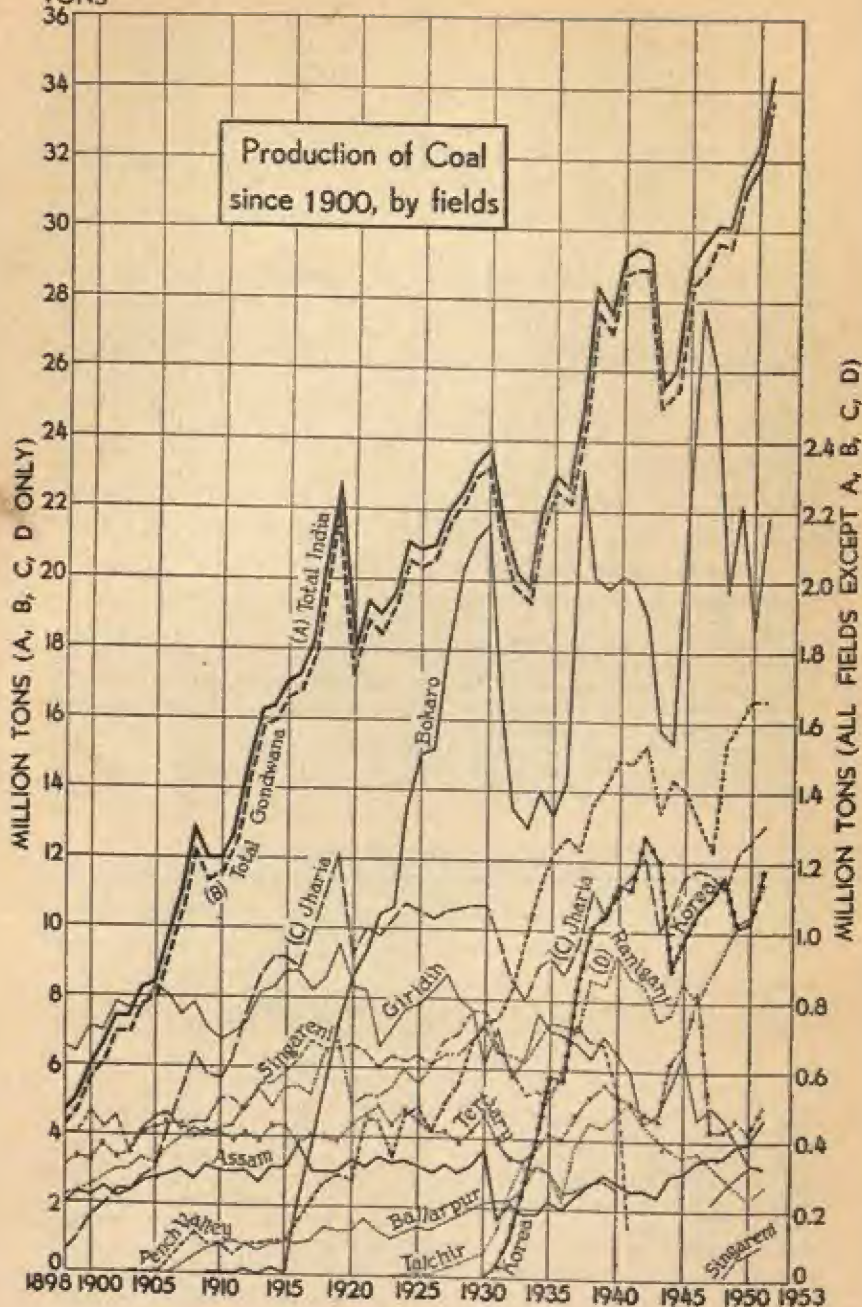
Calorific Values are expressed in British Thermal Units.

These analyses are taken from a report by Dr J. W. Whitaker, Director of the Fuel Research Institute of India.

PRODUCTION OF COAL IN INDIA, 1900-50

YEAR	TONS	VALUE AT MINES		PIT'S MOUTH AVERAGE VALUE PER TON	PROPORTION FROM	
		£	Rs.		GONDWANA ROCKS	TERTIARY ROCKS
					%	%
1900	6,118,692	1,343,081		3.29	94.6	5.4
1901	6,635,727	1,323,372		2.99	94.4	5.6
1902	7,424,480	1,366,909		2.76	95.4	4.6
1903	7,438,386	1,299,716		2.62	95.1	4.9
1904	8,216,706	1,398,826		2 9 0	95.02	4.98
1905	8,417,739	1,419,443		2 8 0	94.95	5.05
1906	9,783,250	1,912,042		2 15 0	95.56	4.44
1907	11,147,339	2,609,726		3 8 0	96.17	3.83

MILLION
TONS

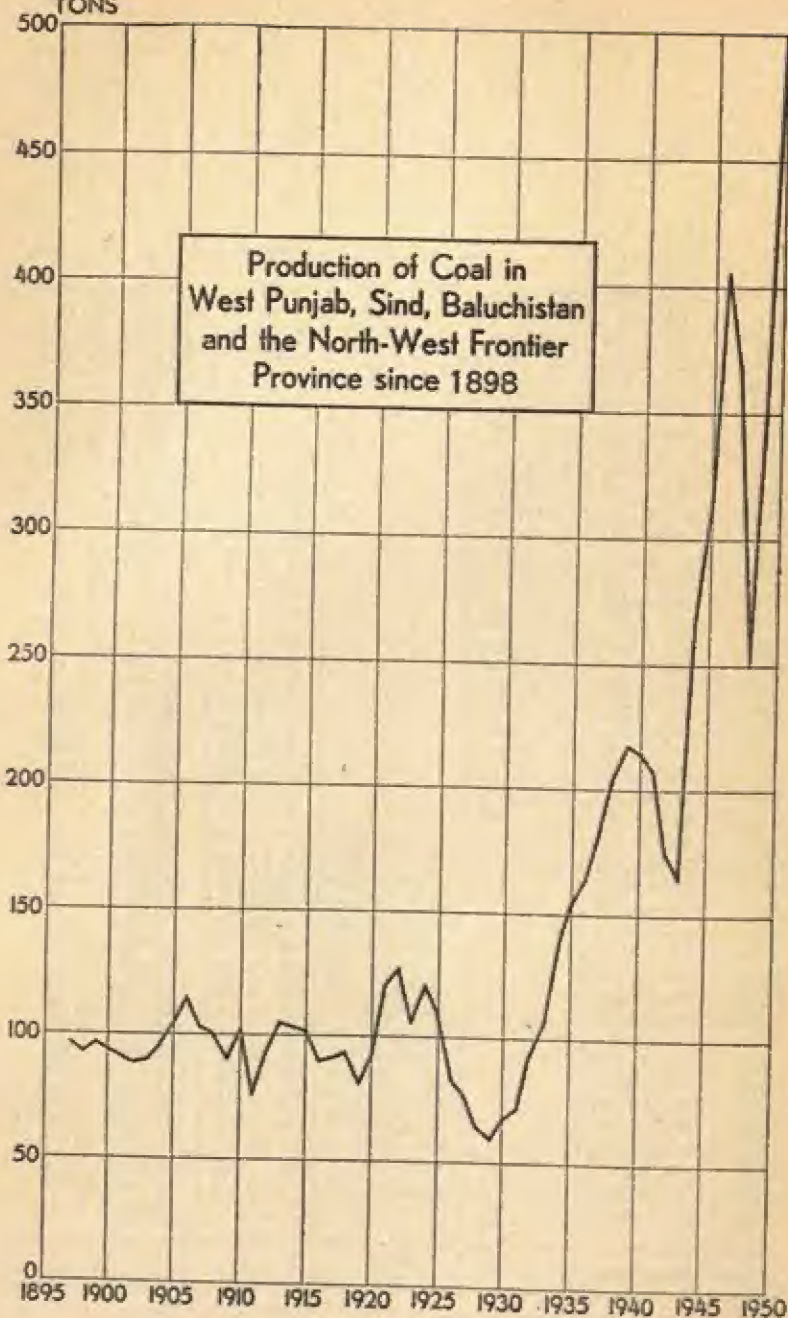


PRODUCTION OF COAL IN INDIA, 1900-50—Continued

YEAR	TONS	VALUE AT MINES		PIT'S MOUTH AVERAGE VALUE PER TON	PROPORTION FROM	
		£	Rs.		GONDWANA ROCKS %	TERTIARY ROCKS %
				Rs. a. p.		
1908	12,769,635	3,356,209		3 15 0	96·90	3·10
1909	11,870,064	2,779,865		3 8 0	96·57	3·43
1910	12,047,413	2,455,544		3 1 0	96·58	3·42
1911	12,715,534	2,502,616		2 15 0	96·96	3·04
1912	14,706,339	3,310,365		3 6 0	97·23	2·77
1913	16,208,009	3,798,137		3 8 0	97·57	2·43
1914	16,464,263	3,907,380		3 9 0	97·42	2·58
1915	17,103,932	3,781,064		3 5 0	97·48	2·52
1916	17,254,309	3,878,564		3 6 0	97·74	2·26
1917	18,212,918	4,511,645		3 11 0	97·81	2·19
1918	20,722,493	6,017,215		4 6 0	98·08	1·92
1919	22,628,037	8,799,353		4 8 0	98·28	1·72
1920	17,962,214	9,297,853		5 3 0	97·58	2·42
1921	19,302,947	8,673,377		6 12 0	97·62	2·38
1922	19,010,986	9,755,343		7 11 0	97·43	2·57
1923	19,656,883	9,737,316		7 7 0	97·77	2·23
1924	21,174,284	10,766,433		7 1 0	97·75	2·25
1925	20,904,377	9,503,828		6 1 0	97·82	2·18
1926	20,999,167	7,574,599		4 13 0	98·02	1·98
1927	22,082,336	7,079,852		4 5 0	98·11	1·89
1928	22,542,872	6,604,106		3 15 0	98·27	1·73
1929	23,418,734	6,668,591		3 13 6	98·22	1·78
1930	23,803,048	6,861,134		3 14 3	98·06	1·94
1931	21,716,435	6,125,804		3 12 11	98·22	1·78
1932	20,153,387	5,120,045		3 6 1	98·32	1·68
1933	19,789,163		6,11,77,739	3 2 0	98·32	1·68
1934	22,057,447		6,30,60,951	2 13 9	98·34	1·66
1935	23,016,695		6,52,20,840	2 13 4	98·22	1·78
1936	22,610,821		6,24,98,404	2 12 0	98·24	1·76
1937	25,036,386		7,81,02,439	3 2 0	98·13	1·87
1938	28,342,906		10,64,23,835	3 12 0	98·17	1·83
1939	27,769,112		9,87,23,916	3 9 0	98·01	1·99
1940	29,388,494		10,51,65,232	3 9 0	98·19	1·81
1941	29,463,742		10,76,79,014	3 10 0	98·28	1·72
1942	29,433,253		13,09,05,064	4 7 0	98·36	1·64
1943	25,511,909		16,95,07,329	6 10 0	98·22	1·78
1944	26,126,676		27,23,92,131	12 12 6	97·63	2·37
1945	29,167,152		32,80,99,008	14 3 4	97·70	2·30
1946	29,766,018		35,73,87,713	12 0 0	97·43	2·57
1947	30,144,505		43,77,20,245	14 9 0	98·61	1·39
1948	30,124,175		45,20,56,474	15 0 0	98·57	1·43
1949	31,695,375		47,56,36,921	15 0 0	98·61	1·39
1950	32,307,481				98·69	1·31
TOTAL	1,022,364,253					

NOTE :—The production of Pakistan is included up to the end of 1946.

THOUSAND
TONS



AVERAGE ANNUAL IMPORTS OF COAL INTO INDIA, 1900-45 (Long Tons)

Arranged according to Countries

PERIOD	UNITED KINGDOM	AUSTRALIA	UNION OF SOUTH AFRICA	PORTUGUESE EAST AFRICA	JAPAN	OTHER COUNTRIES	TOTAL
1900-1 to 1902-3 ..	173,515	13,520	....	....	29,460	2,442	218,937
1903-4 to 1907-8 ..	190,158	23,643	8,090	....	21,904	4,476	248,211
1909-13 ..	229,526	52,393	71,604	....	43,908	68,730	465,161
1914-18 ..	471,128	20,247	29,782	29,280	19,805	11,279	148,521
1919-23 ..	265,236	40,015	170,144	90,886	26,719	11,941	604,941
1924-8 ..	73,001	11,792	148,560	75,787	4,666	5,048	318,914
1929-33 ..	23,001	2,790	95,359	1,042	798	4,709	127,699
1934-8 ..	16,657	3,472	36,265	5,591	1,070	8,296 ⁽¹⁾	71,351
1939-43 ..	3,126	....	8,707	....	....	2,928 ⁽²⁾	14,761
1944-6 ..	193	....	2,782	....	....	337 ⁽³⁾	3,312
Total ..	4,760,589	812,320	2,850,601	1,019,930	637,730	595,372	10,669,542
PERCENTAGES ..	44.7%	7.6%	26.7%	9.5%	5.9%	5.6%	....

⁽¹⁾ includes an average of 7,308 tons from Germany.⁽²⁾ " " " " 795 " of coke.⁽³⁾ " " " " 288 " of coke.

Over the years 1947 to 1950 (inclusive), a total of 219 tons of coal were imported into India, all of which came from the United Kingdom.

AVERAGE ANNUAL EXPORTS OF COAL FROM INDIA, 1900-46 (Long Tons)

Arranged according to Destinations

PERIOD	UNITED KINGDOM	ADEN	BURMA	CEYLON	MAURITIUS	STRAITS SETTLEMENTS	HONG KONG	CHINA
1900-3 (*)	....	40,571	....	325,897	13,064	81,624	....	....
1904-8 (*)	....	24,077	....	360,427	9,550	203,724	....	....
1909-13 ..	....	8,084	....	406,965	2,423	187,523	45,356	....
1914-18 ..	....	9,422	....	359,496	837	88,782	....	....
1919-23 ..	....	22,954	....	282,951	....	74,284	....	....
1924-8 ..	10,272	13,353	....	260,421	984	74,956	24,308	....
1929-33 ..	20,215	1,496	....	270,352	1,575	30,879	141,359	2,294
1934-8 ..	....	4,786	201,799	231,415	2,032	24,383	37,662	65,032
1939-43 ..	....	2,761	296,960	305,648	....	87,691	94,224	212,457
1944-6 ..	....	....	....	64,008	....	....	....	....
TOTAL EXPORTS..	152,435	556,378	2,493,795	13,858,085	126,297	4,105,992	1,714,545	1,398,915
PERCENTAGE OF TOTAL ..	....	1.9%	8.7%	48.3%	....	14.3%	5.9%	4.8%

(*) fiscal years.

ANNUAL EXPORTS OF COAL FROM INDIA, 1947-50 (Long Tons)

YEAR	ADEN	CEYLON	WESTERN PAKISTAN	OTHER COUNTRIES	TOTAL	VALUE Rs
1947	..	137,648	..	409,983	550,526(1)	1,52,01,387
1948	1,180	249,346	372,646	311,349	948,288(2)	3,28,66,182
1949	..	312,567	487,898	464,498	1,267,267(3)	4,17,00,092
1950	6,123	295,241	..	601,781	910,844(4)	3,47,34,182
TOTAL	7,303	994,802	860,544	1,787,611	3,676,925	12,45,01,843

(1) includes 2,895 tons coke

(2) " 13,767 " "

(3) " 2,304 " "

(4) " 7,699 " "

PRODUCTION OF COAL IN WEST PAKISTAN (TONS)

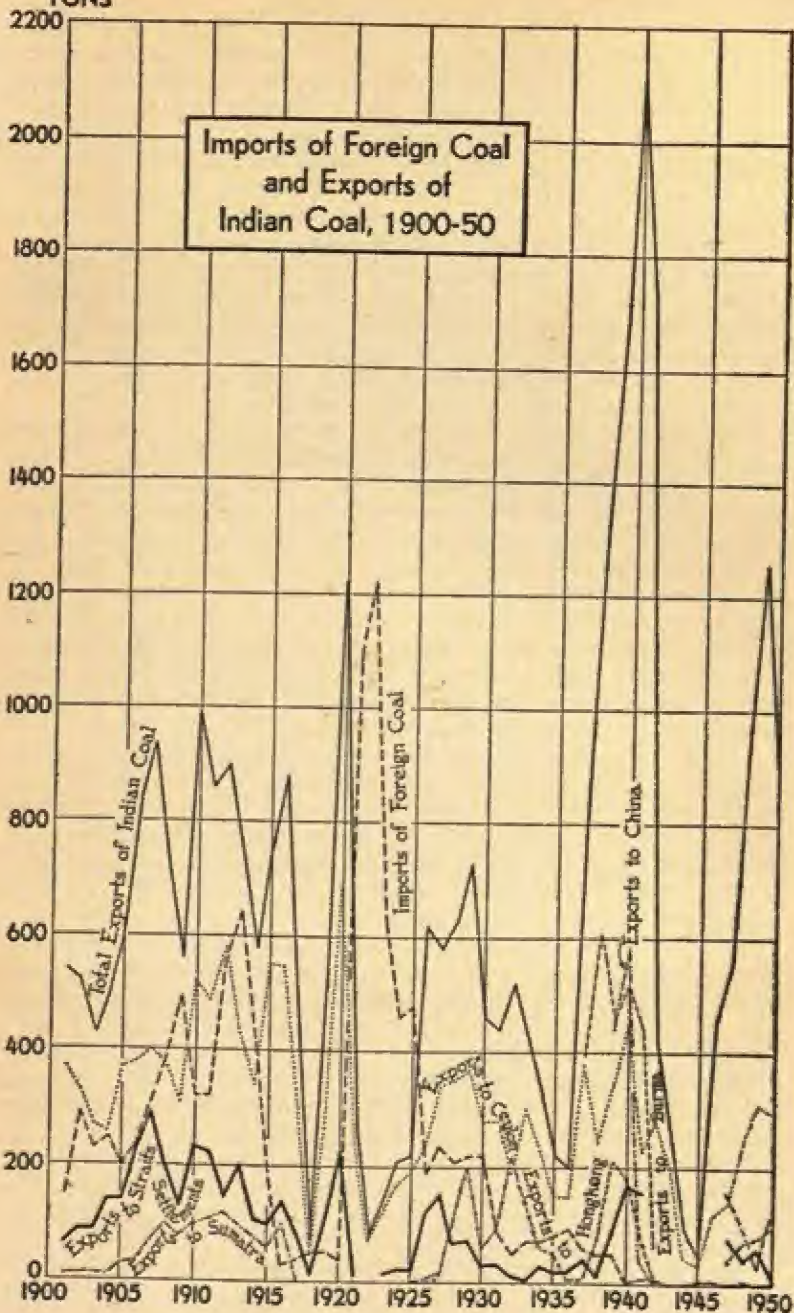
YEAR	BALUCHISTAN	WEST PUNJAB	TOTAL
1946	197,505	192,706	390,211
1947	182,290	175,454	357,744
1948	95,935	144,822	240,777
1949	145,350	178,722	324,072
1950	237,847	192,750	430,597

PEAT

The first stage in the development of many types of coal is represented by the peat deposits of present and comparatively recent times. They are the result of the slow accumulation of partially decayed vegetation under the waterlogged conditions prevalent in bogs, swamps and marshes in which the remains of the mosses, reeds and grasses adapted for such situations are neither removed nor thoroughly decomposed but serve as a foundation for the next crop of younger growth as season follows season. In this way a succession of layers is slowly built up—living plants at the top, their recognizable remains at lower depths, until in the bottom layers little trace of their original structures is left. When deeply buried and compressed in the course of geological time peat passes into the brown coals and lignites.

In its raw state peat contains about 80 per cent of moisture, but by suitable stacking and air-drying this can be reduced to about 20 per cent. Such air-dried peat is still used in isolated districts as a slow-burning fuel though its calorific value is stated to be only about half that of an equal weight of good coal. Even in countries possessing very extensive deposits, the problems

THOUSAND
TONS



connected with the large-scale profitable utilization of peat for commercial purposes remain unsolved, owing to the high cost of winning, handling, drying and preparing it for the market in competition with other fuels. Owing to its absorbent properties dried peat makes a good stable litter and then forms an excellent manure. It is increasingly employed in Europe in the preparation of horticultural composts and, in the form of dust, as a packing for fruit and vegetables for transit by sea, air or railway. After the addition of chemical fertilizers it is utilized as a top dressing for grass and other farm crops.

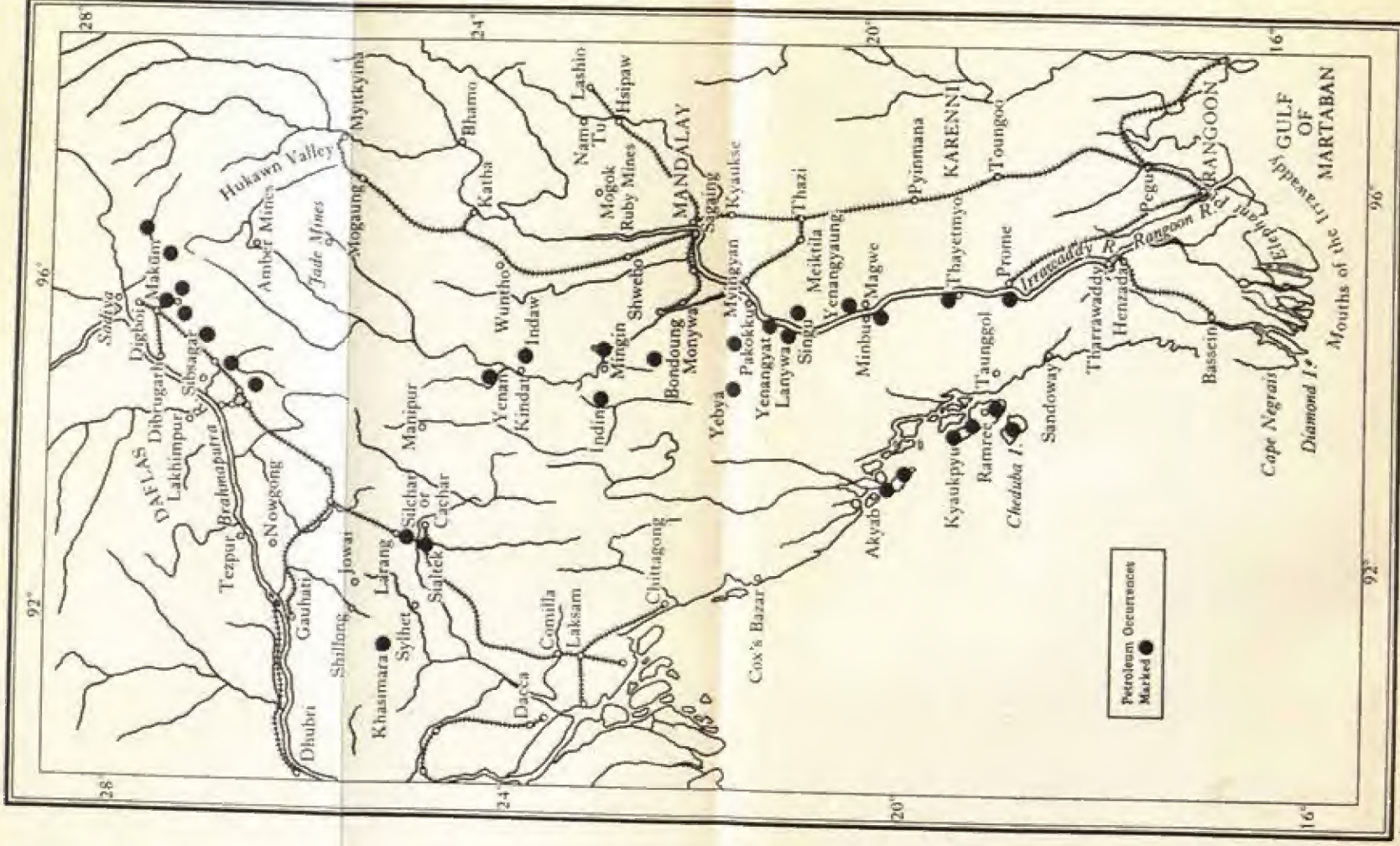
Peat deposits are more characteristic of cold, temperate climates such as those of northern Europe and Canada than of warm tropical regions where the decay of plant life is usually rapid and complete; but even in such countries special conditions of altitude and environment are occasionally found in which peat, or deposits of an analogous character, have been laid down.

Perhaps the nearest relatives of the true peats of northern latitudes are the bog peats of the Nilgiri Hills of Madras. These lie in surface hollows at elevations of over 6,000 feet above sea level, where the local flora shows affinities with that of the Palae-arctic region, where *Sphagnum* moss prevails extensively as it does in the peat bogs of northern Europe and where identical genera of associated plants are present. Dried Nilgiri peat was at one time used as fuel in Ootacamund and, about 1870, the possibility of employing it in place of coal for locomotives on the Indian railways was discussed. Beyond the fact that in places some Nilgiri peat deposits are said to be 30 feet deep, nothing is known as to their real extent or average composition.

In the Shevaroy Hills of the Salem district, Madras, peat is reported to form at elevations of over 4,000 feet. According to H. B. Medlicott, beds of serviceable peat are of frequent occurrence at various levels in the valley of Nepal, particularly about the Katwaddar gorge and to the north of Katmandu where it is used as fuel for both brick and lime kilns. Similar material has also been found in the Vale of Kashmir.

Of quite a different character are certain deposits to which the name 'peat' has been applied, probably for want of a more suitable term. These include the masses of decayed vegetation of a peaty appearance which form at the bottom of the *jhils* of Sylhet, Cachar, of the Brahmaputra valley and of the marshes of the deltaic districts of East and West Bengal. The stalks of the tall, marsh-loving wild rice, *Oryza sylvestris*, make up the bulk of such deposits together with the remains of water-lilies (*Nymphaea*) and of aquatic submerged herbs such as *Valisneria*. These materials are sometimes used as manures but are unlikely to form useful fuels. A *jhil* near Kindauli, in the Partabgarh district of Uttar Pradesh, contains a deposit of a similar character.

Yet another variety of 'peat' occurs at varying depths below the surface in the alluvial deposits of the Gangetic delta. A bed



Scale, 1 inch = 114 miles

Brown & Dey, India's Mineral Wealth, facing p. 85

OCCURRENCES OF PETROLEUM IN ASSAM & BURMA

Taken with permission from *Quinquennial Review of Mineral Production of India*, and certain additions made.

of this type is traceable over a wide area about 30 feet below the surface, on both sides of the Hooghly river, in the neighbourhood of Calcutta. As it contains both the stumps of coastal *sundri* trees (*Heritiera littoralis*) and of aquatic plants such as *Euryale ferox*, it appears to be of composite origin. Generally speaking it is too impure for use as a fuel, even if it were practicable or desirable to hazard mining operations in such a situation. To geologists these peat beds are marker horizons of the amount of subsidence of the land which has taken place since their formation, a matter of some importance in the vicinity of a great city.

Southern India too can furnish examples of much the same kind of buried, coastal swamp peats; thus R. B. Foote and W. King mention a peat bed exposed at low tide in the alluvium of the estuary of the Vellar river, at Tolum in the South Arcot district of Madras, in which the leaves and fruits of dicotyledonous trees are still visible. Further south still, Dr M. S. Krishnan has related how peat was discovered in the Tanjore district, in 1828, at a depth of 17 feet below the surface, at a location 'near the promontory about 20 miles from Cape Calimere'. This bed is over 5 feet in thickness, full of vegetable remains, including the bark and branches of trees, and possibly extends along the coast for upwards of 30 miles. The preservation of this particular deposit was perhaps due to the same general subsidence of the coast responsible for the submerged forest at the western end of Valimukkam Bay in Ramanathapuram district.

In West Pakistan, states W. T. Blanford, peat occurs 'about half a mile west of the station at Quetta and occupies a considerable area of marshy ground. It is not very pure as it is somewhat mixed with earth but it closely resembles that found in Europe.'

The surface peaty deposits of the Shan plateau of Burma are formed by rank growths of aquatic plants and grasses in gently undulating situations, where stagnant conditions of drainage exist, as, for example, in the vicinity of Nawngkhio, on the southern side of the Gokteik gorge. Underground peats probably exist in the upper layers of some of the lacustrine deposits of the Shan States, as they do in the corresponding beds on the eastern side of the frontier in the Chinese province of Yunnan.

Few analyses of Indian peats are available and most of them are old, unrepresentative of the deposits as a whole and liable to be misleading. A re-examination of the whole subject would doubtless lead to results of scientific interest, but the known deposits are unlikely to prove of much practical importance.

PETROLEUM

The oil-bearing regions of Burma, India and Pakistan occur in the Tertiary rocks of the Chindwin-Irrawaddy, Assam-Arakan and Punjab-Sind-Baluchistan belts respectively, forming, as it were,

a link between the oilfields of Borneo, Java and Sumatra on the one hand and those of Iran, Saudi Arabia and Iraq on the other.

OILFIELDS OF BURMA

In the extreme south, the two arms of the Tertiary belt of Burma are separated by the alluvial, deltaic deposits of the Irrawaddy, but further northwards they unite about Prome and continue northwards for over 700 miles into the Upper Chindwin valley, with a maximum width of 120 miles, bordered on the east by the outer fringes of the Shan Plateau and on the west by the foot-hills of the Arakan Yoma. The Tertiary rocks themselves are of great thickness, the Middle and Lower Eocene alone having been estimated to possess a thickness of 25,000 feet. The Upper Eocene consists of the Pondaung Sandstones, up to 6,500 feet thick, followed by the rocks of the Yaw Stage which range between 1,000 and 2,000 feet in thickness.

Above the Eocene comes W. Theobald's 'Pegu System', a name which he applied to all the beds between the Eocene 'Nummulitics' and the Irrawaddy (Fossil Wood) System. The subdivisions of the Pegu System, of great consequence from the point of view of petroleum prospecting, have undergone many changes over the years, but thanks mainly to the work of the geologists of the Burmah Oil Company, they are now definitely established as shown in the Table below. Although the junction of the Yaw Stage of the Upper Eocene exhibits no apparent

THE TERTIARY SUCCESSION IN BURMA

DIVISIONS	SUBDIVISIONS	THICKNESS (feet)	EUROPEAN TIME SCALE (approx.)
Irrawaddy System	UNCONFORMITY	More than 10,000	Pliocene and U. Miocene
Pegu System	Obogon Alternations ..	Up to 3,000	Vindobonian M. Miocene
	Kyaaukkok Sandstones ..	Up to 5,000	Burdigalian L. Miocene
	Pyawbwe Stage ..	Up to 3,000	Aquitanian L. Miocene
	UNCONFORMITY		
	Okhmintaung Sandstones	0-5,000	Chattian U. Oligocene
Nummulitic System	Padaung Clays ..	Up to 2,500	Rupelian M. Oligocene
	Shwezetaung Stage ..	2,000-4,000	Sannoisian L. Oligocene
	Yaw Stage ..	1,000-2,000	Bartonian U. Eocene
	Pondaung Sandstones.	Up to 6,500	Auverian U. Eocene
	Tabyin Clays		Lutetian M. Eocene
	Tilin Sandstones		Cuisian L. Eocene
	Laungsha Shales with Paunggyi	Up to 25,000	Sparnacian L. Eocene
	Conglomerate		Thanetian Palaeocene
			Montian Palaeocene

This table combines the results of the Geological Survey of India and the Burmah Oil Company as given by F. E. Earnes and H. R. Tainsh.

unconformity with the lowest Shwezetaung Stage of the Oligocene, the scanty fauna of the latter contrasts strongly with the richness of that of the former. The Shwezetaung Stage, from 2,000 to 4,000 feet thick, displays marked lateral variation and is followed upwards by the Padaung Clays, up to 2,500 feet of shales and mudstones, in spite of their name: of Middle Oligocene age, they are succeeded by the Okhmintaung Sandstone, attaining a maximum thickness of 5,000 feet, but varying greatly, and in some localities entirely removed by the uplift and subsequent erosion which happened towards the end of Oligocene times.

The break in the succession which divides the Pegu System into two parts at the Oligocene-Miocene boundary is no small, local event for it is even more strongly developed in Assam, where it occurs between the Barail Series and the Surma Series; it is especially pronounced in the Punjab, where the Murree Series of Lower Miocene age rests on various members of the Eocene and the Oligocene is entirely absent, and it has been recognized recently in Sind between the Upper and Lower Nari subdivisions, according to Eames (1950).

The Burmese Miocene has three subdivisions, the Pyawbwe Stage up to 3,000 feet thick, in places having a massive development of sandstones at its base, but otherwise largely of shales and sandstones, containing many characteristic Miocene lamellibranchs; the overlying Kyaukkok Sandstones, which may attain 5,000 feet, and carry a rich, molluscan fauna with a large proportion of gastropods and, lastly, the Obogon Alternations which are only present where the erosion associated with the unconformity between the Irrawaddy and Pegu Systems has been comparatively slight. The deposits of the Irrawaddy System are of continental and fluvial types, thick conglomerates, grits and false-bedded, ferruginous sands with a few subordinate clays; silicified wood is very abundant in them and mammalian remains similar to those of the Siwaliks of north-west India are found in the lower horizons.

In studying the stratigraphy of the oilfields of Burma, it is important to remember that in late Eocene, part of Oligocene and Miocene times, the sediments deposited in the Tertiary gulf to the north of the main oilfields were generally of a non-marine character, while further to the south, the prevailing conditions were essentially marine. As Tainsh has pointed out, similar events are proceeding today in the Brahmaputra valley and the lower Irrawaddy basin, where, within much the same tectonic framework, fluvial, deltaic and marine sediments are being contemporaneously and rapidly deposited.

The Burma Tertiary basin is divided into four structural units as follows:—(1) a Northern or Chindwin Basin, north of Latitude 22° , separated by a transverse uplift from (2), the Central Basin, lying between Latitudes $19^{\circ} 30'$ and 22° , and separated in its turn

from (3), the Southern Basin, by an uplift about Latitude $19^{\circ} 30'$. The fourth unit comprises the Pegu Yoma with its north and south trending, packed folds, extending as far as Latitude 24° . Between Latitudes 19° and 20° branching folds stretch north-west, across the prevalent regional strike, and merge with the western margin of the Central Basin. The folds on the eastern sides of the Northern and Central Basins are usually overthrust towards the east, and on their western sides the beds as a rule dip easterly, though there are also strike faults and some subsidiary folding.

In the Northern Basin all the surface oil shows are in the Upper Eocene rocks, particularly in the uppermost part of the Pondaung Sandstones, but the oilsands of its only known field are in Miocene or Oligo-Miocene strata. In the Central Basin, although most of the surface oil shows are in the Eocene, there are others at higher horizons and the production of the oilfields comes mainly from Oligocene and Miocene rocks ranging from the Shwezetaung to the Kyaukkok Sandstones. In the Southern Basin oil seepages have not been found in the Eocene, but there are a few in higher horizons, mainly of Miocene age. In the following descriptions the oilfields are traced from north to south.

Indaw. Within the main syncline of the Northern Basin and lying across its central line is the anticline of Indaw, on which is located its solitary oilfield, about 175 miles north of any of the other important fields. Situated 22 miles inland from Pantha, on the east bank of the Chindwin river in the Upper Chindwin district, it is an asymmetrical, elongated dome with a gentle west flank dipping about 10° to 15° , and a steeply dipping (50° to 65°) eastern one. It is some 9 miles long and 2 miles across at its widest point, and in its southern half possesses a subsidiary crest parallel to the main one and about half-a-mile from it on the west. Its Pegu rocks are predominantly sandy in character, but there are also alternations of sands and clays, especially in the lower horizons. The bulk of the production came from shallow sands, between 800 and 1,200 feet from the surface, and deep tests have proved difficult owing to the presence of gas sands under high pressures below the main oil horizon. Indeed the natural gas resources of the field appear to be large. The oil was piped to a refinery at Pantha and the finished products were distributed to various markets in Upper Burma before the Japanese occupation of the country. The Indo-Burma Petroleum Co. Ltd commenced drilling on the Indaw field in 1912, but the prevalence of malaria and the difficulties of transport in this isolated region hampered progress, so that it was not until 1918 that commercial production was obtained. The output rose to a maximum of 4,040,690 gallons in 1932, after which there was a gradual decline to 2,014,072 gallons in 1938. During these 37 years of its life the Indaw field had yielded a total of 45,638,075 gallons of oil.

Sabe-Yenangyat. These fields, together with the more southerly one of Lanywa, lie to the west of the Irrawaddy, on the long inlier of Pegu rocks which, south of the river, continues into the Singu or Chauk oilfield. They are all, together with the Yenangyaung and Miubu fields, in the Central Basin. The whole outcrop of the rocks of the Pegu System has a length of 39 miles and a maximum breadth of $3\frac{1}{2}$ miles, trending north-north-west to south-south-east with its steep eastern scarp lying for half its length close to the western bank of the Irrawaddy. The anticline is remarkably asymmetrical; its gentle, western flank rising at about 15° to 20° while its thrust-faulted eastern one is very steep, sometimes vertical and in places overturned. The pitch of the fold itself and the positions of three high portions of its crest account for the oil pools at Sabe, in the north, around Yenangyat itself, some 12 miles further south, and again in a locality about 5 miles further south still.

T. Oldham, the first Director of the Geological Survey of India, who was at Yenangyat in 1855, suggested that it might be worth while exploiting and hand-dug wells seem to have been started about 1864, though 'springs of petroleum' in this neighbourhood had been mentioned by Buckland in 1827. Machine drilling was commenced in 1893 and although the wells have often started with big initial yields, they declined rapidly and production has never been high. Most of the oilsands are shallow, from 500 to 1,500 feet below the surface, near the summit of the long, narrow, Yenangyat field proper. On the small Sabe field which was first developed in 1908, oilsands occurred down to 1,800 feet, but they proved to be thin, with poor yields, and production ceased there in 1922.

Starting with 118,400 gallons in 1893, the maximum output of the whole field was reached in 1903, with $22\frac{1}{2}$ million gallons, but the inevitable decline though slow at first became accentuated later, and in the five years ending 1928 production averaged only 1,970,434 gallons per annum. From 1928 onwards the official returns include the output for the Lanywa field, doubtless an advantage to the revenue statistician but a considerable loss to the petroleum geologist. The production of Yenangyat alone immediately before the Japanese invasion was however about 5 million gallons annually, and the field has hitherto yielded about 290 million gallons. The Yenangyat and Singu (Chauk) fields were connected by a pipeline, and the latter was joined in the same way with Yenangyaung, whence another line led to the refineries at Syriam, near Rangoon.

Lanywa. The Lanywa and Singu oilfields lie on a major dome of Pegu rocks, the axis of which is slightly *en échelon* with that of the Yenangyat field, a fact of great economic significance overlooked by the earlier investigators who considered the prospects of the Lanywa area, so far south of Yenangyat, as hopeless. The

geologists of the Indo-Burma Petroleum Co., however, established the fact of this slight off-setting and decided that Lanywa belongs to the Singu rather than to the Yenangyat folding.

The anticlinal crest crosses the Irrawaddy obliquely and rich oilsands lie under its bed. In 1914 a well was started on a sand-bank in the river to the south of Lanywa but as this became submerged during the flood season, the Government of the day ordered its removal as a menace to boat traffic. In 1919 another well was drilled on a sand-bank projecting from the shore and it obtained oil from two sands. By 1929 the Company had completed an embankment for its protection, and by the end of 1930 there were 17 producing wells on the reclaimed area, with a yield for the year of 17½ million gallons.

A total of over 100 wells has been drilled, and many of them have been inclined from the vertical to reach the oilsands beneath the river. Some of these inclined wells have deviations up to about 45° and have been completed as much as 1,700 feet away from a point vertically below the top of the well. The Indo-Burma Petroleum Company's development of the sands beneath the river represents a remarkable technical achievement. The highest production obtained was in 1935, when 23 million gallons came from Lanywa, and the total production prior to the Japanese invasion was about 250 million gallons.

Singu (Chauk). The Singu, or Chauk, oilfield is the continuation on the opposite (left) bank of the Irrawaddy of the Lanywa field just described. It comprises the southern end of the 39 miles long anticline which stretches northwards through Lanywa, Yenangyat and Sabe. This portion of the Pegu inlier, with its exposed length of about 6½ miles and an average breadth of 2 miles, was first recognized by G. E. Grimes of the Geological Survey of India in 1897. Like its sister fields to the north, it is a pronounced, asymmetrical, elongated dome, with dips on its western flank of 10° to 15° increasing gradually to 20° to 25°, while on the eastern flank dips of 80° to vertical, or, in places, slight overturning are met with. The presence of a thrust fault in association with the steep eastern flank has been recently demonstrated. In the southern part of the field, the anticlinal crest pitches at 5° towards the saddle which lies between it and Yenangyaung.

Below the blanket of the Irrawaddian, the members of the Upper Pegu System comprising the Kyaukkok Sandstones, 500 feet in thickness, and the Pyawbwe Clays, 1,100 feet thick, are exposed, together with the upper portion of the Okhmintaung Sandstones (1,700 feet in all). The remaining stages which belong to the Lower Pegu, the Padaung Clays (3,600 feet thick) and the Shwezetaung Sandstones of unknown thickness, lie below the surface but are penetrated by the wells. The proved oilsands occur in the upper part of the Padaung Clay, which, in spite of its name, and its

great thickness of marine shales, contains sandy, oil-bearing bands of varying lateral extent, 20 to 50 feet thick. Although entirely buried in the Singu-Lanywa dome, these clays are partially exposed at the surface further north in the Yenangyat field. The Shwezetau Sandstones have only been reached by a few wells in the Singu field and have not yielded oil as yet, but they contain some producing wells in Yenangyat.

The major portion of the field was leased to the Burmah Oil Co. Ltd and the first well was drilled in 1902; since then more than 1,000 wells have been completed by this concern, the Indo-Burma Petroleum Co. Ltd, the Pyinma Development Co. Ltd and the British Burma Petroleum Co. Ltd. At the end of 1938, there were 562 wells in production. There are said to be about 35 oilsands, varying from 10 to 50 feet in thickness, the oil pools lying at depths of 1,200 to 3,800 feet on the western flank, except in an area south of a large cross fault in the south of the field where they are found at depths of from 3,500 to 5,000 feet. New wells usually flowed for short periods, but most of them were pumped or drained by gas-lift. Following the success of the training wall and reclamation on the west bank of the river at Lanywa by the Indo-Burma Petroleum Co., the Burmah Oil Co. constructed one on the east bank, no simple engineering undertaking in a river with an annual rise of 40 feet and a swift current: eighty-three acres of productive territory, since extensively drilled, were recovered by this means from the bed of the river. For the five years ending 1938, the average annual production of the Singu field alone was 101,212,170 gallons, and in that year its record of 120,769,811 gallons passed the annual production of the Yenangyaung field (113,017,514 gallons) for the first time. In 1939, Singu gave 139,792,004 gallons and during the 38 years of its existence it has yielded a total of over 2,728 million gallons of crude oil, characterized by its paraffin base and high wax content.

Yenangyaung. Thirty-five miles south of Singu lies Yenangyaung, the richest oilfield of Burma, some 2 miles east of the Irrawaddy and near the town of the same name, in the Magwe district. It is an elongated dome of Pegu rocks on the same main line of folding as the Singu, Lanywa and Yenangyat fields. Slightly asymmetrical, with dips up to 40° on its eastern and up to 50° on its western flank, it is crossed by numerous transverse faults and is about 6 miles long and one mile wide, though its chief producing area covers only a portion of this. From beneath the overlying Irrawaddian rocks, a portion of the Lower Miocene, Kyaukkok Sandstones of the Upper Pegu, is exposed at the surface. According to Tainsh, writing in 1950 with the permission of the principal oil companies concerned, these Kyaukkok beds consist of 1,400 feet of false-bedded, coarse-grained sandstones, with alternations of sand and shale, and with gypsum-bearing shales. Under them,

but not exposed at the surface, are the blue clays and shales of the Lower Miocene Pyawbwe Stage; 1,400 feet thick, they contain many thick sand beds and fossiliferous marine bands. Below the Pyawbwe Stage come the Upper Oligocene shallow water, false-bedded, marine sands of the Okhmintaung Stage, 1,000 feet thick, with subordinate shale bands and several well-known marker horizons of harder, cemented sandstones or breccias. The downward succession is completed by the rocks of the Middle Oligocene Padaung Stage, perhaps 3,900 feet thick, and by the underlying Shwezetaus about which little is known. The upper part of the Padaung Stage carries alternating bands of sand and shale, the former generally about 20 feet thick. The lower part is almost entirely shale with very few sand intercalations.

The Yenangyaung field differs from Chauk in the much smaller degree of asymmetry, the greater number of cross faults, and in the number and stratigraphical range of the oilsands. In Chauk, only the upper sands in the Padaung Clays have yet been proved to carry oil, whereas at Yenangyaung oilsands range from the lower part of the Kyaukkok Sandstones, through the Pyawbwe Stage and Okhmintaung Sandstones into the rocks of the upper part of the Padaung Stage, comprising a stratigraphical thickness of 4,500 feet of strata. No oil has yet been found in the lower part of the Padaung Stage, while the Shwezetau Sandstones, lying at depth, have still to be thoroughly tested. Altogether there are over 50 oilsands varying in thickness from 10 to 150 feet, and found at all depths from the surface to 5,500 feet. For productive purposes they are divided into Shallow, Intermediate and Lower Sands, and the oil pools of each are developed by separate sets of wells. The shallower pools occur near the crest and are up to 2,600 feet in width. The oil pools of the Okhmintaung Stage are found at the crest in some parts of the field and on the eastern flank in others, in which case the crestal areas are gas-bearing. The pools of the Padaung Stage lie on the eastern flank with large original gas-caps.

A primitive form of oil mining has been practised for centuries by the Burmese on the Yenangyaung and certain other fields, by sinking narrow, timbered shafts to sands at depths of from 200 to 400 feet and baling the oil from them. Under the Burmese monarchs the rights to carry on oil mining were vested in 24 families and their hereditary claims over two tracts of 295 and 155 acres, known as the Twingon and Beme reserves of the Yenangyaung field, were recognized and preserved by the British Government after the annexation of Upper Burma in 1885, a specified number of well sites (circles of 60 feet diameter) being allotted to each family annually until the whole area had been distributed. The output from the hand-dug wells was about $2\frac{1}{2}$ million gallons per annum in 1888. The use of modified diving dresses by the shaft sinkers enabled them to reach greater depths and to obtain more

oil, so that by 1900, hand-dug production had increased to 8½ million gallons. After 1908, however, a rapid decline followed as the hereditary families sold and leased their well sites to the European companies, yet no less than 195 wells of this type were still in operation in 1938, for the oil from them has its special uses and an old-established market up and down the Irrawaddy valley.

Modern exploitation dates from 1887, when the Burmah Oil Co. Ltd commenced drilling in Khodaung, the central area which together with other parts of the field is leased to it. The first well was but 727 feet deep and others were still shallower; one of them, B.O.C. No. 8, 350 feet deep, is known to have yielded oil for over 50 years and probably could still give a small production. In 1907, the Rangoon Oil Co. Ltd began to lease well sites from the hereditary owners, and other companies soon followed suit, so that eventually the Twingon and Beme reserves became congested with wells, many of them only 60 or 80 feet apart, engaged in competitive production which gravely increased the hazards of fire and flooding. Outside the reserves, in the blocks leased to individual companies, the spacing of the wells followed more normal practice. A total of more than 4,000 wells have been drilled on the field by various concerns, including the Burmah Oil Company, the Indo-Burma Petroleum Company, the British Burmah Petroleum Company (successors to the Rangoon Oil Company) and the Nath Singh Oil Company; out of this total 2,710 wells were producing oil in 1938. In 1930, the discovery at a depth of 4,000 feet or so of an oil-bearing sand in the south of the field led to great hopes for the development of an area hitherto considered to be of little value. Although a well still further south, near the southernmost exposure of rocks of the Pegu System, found some oil at 5,000 feet, further drilling showed the southerly pitching end of the structure to be disappointing. On the eastern flank of the anticline, however, sands between 3,000 and 4,000 feet have given good yields. In the central part of the field very high pressures are met with at depth, and testing has become both difficult and expensive. Several deep wells have been drilled below the developed sands, the deepest reaching 9,705 feet; although some high-pressure water-sands were found, no deep oil had been discovered when the Japanese invasion put an end to all operations on the field.

The output of oil from Yenangyaung was 1½ million gallons in 1890 and increased gradually to 8½ million gallons in 1897, but after 1898 there was a rapid expansion from 14½ million gallons in 1899 to 181 million gallons in 1909. The peak was reached with 203,638,000 gallons in 1916, after which there was a steady decline. By 1939 output had fallen to 106,089,250 gallons, the average for the five years ending 1938 being 126,676,207 gallons. From the commencement of drilling in 1887 to the end of 1939, over 5,675 million gallons of oil had been taken from the Yenangyaung field. The crude oil, like that from Singu (Chauk) and Lanywa, has a

paraffin base, contains a high percentage of low boiling fractions and averages 7.5 per cent wax.

Minbu, Palanyon and Yethaya. A narrow, anticlinal fold in the Pegu rocks, trending approximately north and south, occurs on the right bank of the Irrawaddy and extends more or less parallel to it, 20 to 30 miles south of Yenangyaung. It is an acute fold, slightly overturned in places and overthrust on the east, with steep dips on its western flank, except in the extreme south where they become flatter. The flexure is sharp and deeply denuded; in Sir Edwin Pascoe's words, 'not unlike that of Yenangyat but it has reached a more advanced stage'. It possesses a number of irregularities suggesting an intermittent action on the part of the forces responsible for the folding: these, and its general structure, have resulted in great compression of the beds and in the circumscribed character of the oil pools which have been found at certain favourable positions along the crest. The general direction of the anticlinal axis is 20° west of north to 20° east of south, but there are many local deviations.

In the north, near the town of Minbu, the fold is almost symmetrical with dips of 75° to 80° on the west, but a strike fault, which further south develops into a thrust, occurs a short distance beyond the crest, and to the east of it the beds are vertical or overturned. The Minbu oilfield lies on the northerly, pitching end of the fold and its shallow wells obtain production from sands between 100 and 1,000 feet below the surface. To the south of the town are the mud volcanoes and gas pools, large hollows filled with soft mud through which bubbles of gaseous hydrocarbons exude. Over much of the anticline the thrust has replaced the crest, so that the true, original crest only remains locally and for short distances. The fold also pitches in the south near Yethaya, but over a distance of some 8 miles between Minbu and this place it undulates, and small, irregular domes, often disturbed by cross faults, occur at intervals.

The small dome of Palanyon, 6 miles south of Minbu, is one of these and for several years it yielded oil from sands in the 1,000 to 2,000 foot zone. It lies near the culmination of the anticline which is here sharply asymmetrical with its steeply dipping eastern limb truncated by the thrust fault. One of its wells had an initial production of 5,000 gallons per day, in 1929, accompanied by sufficient gas to satisfy the fuel requirements of this section of the field for some time.

The Yethaya field lies some 4 miles south of the Palanyon dome, on a subsidiary structure developed in the easterly, synclinal limb of the main Minbu field. In addition to shallow wells between the depths of 300 and 600 feet which have been known for many years, several oilsands lying between 900 and 1,900 feet below the surface were exploited later. A deep test well which reached a depth of 5,000 feet, approximately, was abandoned in 1931,

without obtaining oil in profitable quantities. Three miles south of Yethaya, small quantities of oil were obtained from shallow wells at Pepi (Petpe), which lies on the main Minbu structure. It remains to add that in the Minbu anticline the whole sequence of Pegu strata from the Lower Miocene, Kyaukkok Sandstones, down to the Middle Oligocene, Padaung Stage, is petroliferous, but unfortunately its structural abnormalities have either hindered the accumulation of large oil pools or have caused their dispersal after their formation. In the Minbu district as a whole there were 318 producing wells at the end of 1938. Output was first recorded in 1910 and reached a maximum of more than 6 million gallons in 1928, falling to less than half this amount, or 2,818,228 gallons, in 1938. A grand total of 107½ million gallons had been drawn from the various sections of the anticline up to the end of that year.

Padaukpin. The small oilfield of Padaukpin lies about 8 miles west-north-west of Thayetmyo, the headquarters of the district of the same name, on the west bank of the Irrawaddy, south of Minbu. It is sited on a long, steep anticline of Pegu rocks, developed in the trough of a wide, local syncline. The Upper Oligocene, Okhmintaung Sandstones of the Lower Pegu are exposed here, and small quantities of oil were obtained from hand-dug wells in them during the time of the Burmese kings. Early efforts at modern drilling yielded only negligible results, but in 1920 further tests by Indo-Burma Oilfields Ltd led to the expectation of remunerative production. Although about 36 wells were drilled, the total production averaged less than 2,000 gallons per day and within a few years sank to negligible amounts.

Yenanma. Official statistics did not separate the production of the Padaukpin field from that of Yananma, which is located about 20 miles south-west of Minhla, a town on the west bank of the Irrawaddy, in the north of the Thayetmyo district. Three shallow wells were drilled here about 1912 though without much success, but in 1922 deeper drilling by Indo-Burma Oilfields Ltd obtained oil at depths between 300 and 1,200 feet. As there is no clearly defined anticline hereabouts, the mode of occurrence of the oil has been the subject of controversy, though the view usually accepted is that it is associated with a monoclinical structure close to strong cross faults. Four miles farther west are the mud volcanoes of Yegubwet. The total recorded production from the Thayetmyo district up to the end of 1939 was 22½ million gallons approximately. During the better years of its earlier life, the Yananma oilfield used to average about 1,200,000 gallons per annum, but by the period 1930-3 production was only about one tenth of this amount. About 1935, however, an extension of the then known producing area was discovered, and output quickly rose to the record of 2,712,000 gallons by 1938, dropping again to

1,990,376 gallons in 1939. The annual average for the quinquennium 1934-8 was 1,405,725 gallons.

The Arakan Islands. The islands off the Arakan Coast, long noted for their mud volcanoes and the submarine eruptions which occur from time to time in the neighbouring sea, contain oil deposits of doubtful value; though within the territory of the Union of Burma, these occurrences really form the southern land termination of the oil shows of the Assam Tertiary belt. Hand-dug wells have been operated on some of them for an unknown length of time. At the beginning of the present century the outputs of the Akyab and Kyaukpyu districts were roughly 50,000 and 100,000 gallons per annum, respectively, but the output from Akyab slowly dwindled and finally ceased in 1930, while that from Kyaukpyu still languished at a few thousand gallons yearly. In 39 years from 1900, the combined areas yielded a total of 1,983,582 gallons, or less than the Yenangaung field produced in one week in 1939. Special rules were in existence in the days of the British administration concerning the grant of petty leases for oil in the Kyaukpyu district, which were limited to a maximum of one acre and to a duration of ten years.

The Akyab oil came from the Baronga Islands, and although gas vents and oil seepages occur on all three of them, most of the oil was obtained from hand-dug wells, about 300 feet deep, in the southern end of the eastern island. The local rocks consist of sandstones and shales, probably of Miocene and Oligocene age, and the structure is of steep, narrow, overfolded anticlines.

On Ramree Island, of the Kyaukpyu district, there are two small, oil-producing areas, near Minbyin in the northern, and at Ledaung in the southern section, respectively, which first came to the notice of Europeans about a century ago. Several wells were drilled at Yenandaung, in the Minbyin area, by the Canadian system, and although encouraging results were obtained at first, the yields gradually diminished and the industry passed into local hands. The productive wells, generally 250 to 300 feet deep, though sometimes reaching 500 feet, are laid out along two parallel bands about 300 yards apart, which appear perhaps to indicate the presence of an oilsand in the two limbs of a sharply folded and denuded anticline, as the whole region seems to have been crushed into a series of steep, narrow and contiguous folds. At Ledaung, there are two similar bands from which oil has been obtained by means of a few, shallow, hand-dug wells. In the opinion of Sir Edwin Pascoe, folding and denudation have been too severe in these regions to warrant the expectation of oil in large quantities.

In addition to the main oilfields thus briefly described, petroleum is known to occur at many other places in Burma, particulars of which are obtainable in the memoirs by the late Sir Edwin Pascoe,

G. de P. Cotter and E. L. G. Clegg. We also wish to acknowledge our indebtedness to the publications of the geologists of the Burmah Oil Co. Ltd, including those by G. W. Lepper, H. M. Sale, P. Evans, F. E. Eames and H. R. Tainsh.

On 1 April 1937, Burma separated from the former Indian Empire, but the production figures for the oilfields already described have been given up to the end of 1939, the year which witnessed the outbreak of the Second World War. It remains to add that the total production of all the Burmese fields in 1940 was 270,897,782 gallons of oil, together with 11,269,626 gallons of petrol from natural gas. Burma was invaded by the Japanese armies in January 1942 and by the middle of the year the whole country was overrun by them. The wells of all the fields were denied to the enemy, the larger ones plugged with cement and scrap iron, the smaller ones rendered as useless as possible, the power-stations destroyed and the refineries in the neighbourhood of Rangoon severely damaged. Later, the major fields were the scenes of severe fighting and suffered further injuries by bombing and shelling, as well as from Japanese attempts to injure the oilsands as much as possible when the fortunes of war turned against them. After the end of the war in 1945, the rehabilitation of the oil industry was begun, but subsequently progress was greatly handicapped by widespread internal rebellion and unrest which it would be out of place to attempt to follow here. Burma became an independent State in 1948, and by 1950 it was possible, by means of inland water transport convoys under armed escort, to supply northern Burma with the products of a small refinery unit operating on the oilfields. In the state of security then existing, however, the main oil pipeline to Rangoon could not be repaired and for this reason the rebuilding of the main refinery at Syriam could not be completed. Dr Ba Thi of the Burma Geological Department kindly informs us that the production of crude oil in Burma for the years 1949, 1950 and 1951 was 8,671,148, 18,625,979 and 30,055,292 gallons. In November 1951, it was announced that the British Government had offered to lend the Burmese Government a sum of £2,500,000, towards a capital contribution of £5 millions which the Burmese Government were to invest in a joint oil venture with the three British oil companies operating in Burma, the new company to have a capital of £15 millions. Negotiations in connexion with this joint venture to operate the oil-producing and refining industry of Burma are reported to have been concluded with the signing of an agreement in Rangoon on 12 January 1954, under which, it is stated, the Burmese Government immediately acquires a 33 per cent interest in a new concern to be called the Burma Oil Company (1954) Ltd. But at the time of writing the state of the country continues to preclude the prospecting operations on which the long-term future of the industry depends.

OILFIELDS OF ASSAM

The Assam-Arakan geological province to which these oilfields belong stretches for 800 miles from the head of the Brahmaputra valley south-westwards through part of the highlands of central Assam into the Surma valley, thence southwards to the Bay of Bengal near Chittagong and so on to the Arakan coast of Lower Burma. The Tertiary rocks composing it consist in the main of great thicknesses of almost unfossiliferous, monotonous successions of impure sandstones, shales and clays. On the whole it is a deeply dissected region of high relief, heavy rainfall, almost impenetrable jungle and thick soil caps, which render the work of the geological surveyor particularly arduous and difficult.

The outlines of its stratigraphy and structure were due to the pioneering work of F. R. Mallet, Sir Edwin Pascoe, Sir Henry Hayden and other officers of the Geological Survey of India, but the details as they are known today are due to the labours of the geologists of the Assam and Burmah Oil Companies, and especially to the work of P. Evans and H. M. Sale.

The rocks themselves range in age from the Eocene to the Pliocene and are separable into six main divisions. At the bottom is Mallet's Disang Series, a very great thickness, perhaps 5,000 to 10,000 feet of almost unfossiliferous shales, slates and phyllites, best exposed in the Naga Hills and Manipur: near the plains occasional occurrences of foraminifera have shown that the Disang Series includes beds of Eocene age, but farther into the hills it may contain older strata. Equivalent to part of the Disang Series, occurring on the fringes of the Shillong Plateau and Mikir Hills, is the Jaintia Series some 3,000 feet thick, which includes fossiliferous limestones of Ranikot, Laki and Khirthar age. Both the Disang Series and the Jaintia Series are overlain by the Barail Series, 15,000 feet thick, made up of sandstones and shales with, in Upper Assam, a number of coal seams, some of which are thick. This may be partly Upper Eocene, but is now believed to be largely of Oligocene age.

A great break follows the Barail Series, and from comparison with conditions in north-western India and in Burma it is believed to have embraced much of late Oligocene time, and, in places, part of Lower Miocene time. Above this unconformity comes the Surma Series whose 13,000 feet of sandy shales, sandstones and mudstones are of Lower Miocene age. The Tipam Series, 12,000 feet thick, which follows, includes fairly coarse sandstones in the lower part and mottled clays in the upper part, and is of Middle Miocene age. Above another unconformity comes the Dupi Tila Series of sandstones and mottled clays, 10,000 feet thick, which is probably of Upper Miocene (Pontian) age. Finally above the Dupi Tila Series and separated from it by another unconformity are the soft sands and pebble beds of Mallet's Dihing Series which in places reaches a thickness of 11,000 feet, no doubt corresponding

approximately with the Upper Siwaliks of north-western India and the upper part of the Irrawaddy Series of Burma. The thicknesses given for all these rock groups are maxima but they vary greatly from place to place; moreover, the subdivisions of each change markedly from one part of Assam to another, so much so that separate classifications have been adopted by oil geologists for the successions in Upper Assam, the north Cachar Hills, the Surma valley and Arakan. All that we have attempted to do here is to present a broad, general outline of a very heterogeneous system.

The whole of the Assam-Arakan Tertiary belt has undergone strong folding and long, anticlinal axes can sometimes be followed for many miles, the more sharply folded ones being associated with thrust faults. In the north-east, the thrusting has almost obliterated the anticlines and the general structure displays many nearly parallel thrust faults trending more or less north-east and south-west. The most north-westerly member of the whole series closely follows the boundary of the Naga Hills and the plains of the Brahmaputra river, and in places along it, though some anticlinal crests remain intact at the surface, they have usually proved to have been removed at depth by the thrusting. Further to the south-west and south, in the southern Naga Hills and through the Surma valley into the hills of Chittagong and Arakan, folding is more dominant than faulting and asymmetrical anticlines, separated by broader synclines, are more prevalent. In the south of Arakan the structure again becomes more complex.

Both oil and gas seepages are common: in Upper Assam oil shows occur in rocks ranging in age from the Disangs to the Tipam Series, but most frequently in the upper part of the Barail Series and the lower part of the Tipam Series. Occasionally coal seams saturated with oil have been found in the Barail Series. The gas seepages usually occur in *pungs*, an Assamese word denoting a swampy place in which salt water exudes from below. Away from Upper Assam and farther to the south-west, oil shows occur in the Barail and Surma Series, especially near the head of the Surma valley. Still farther south-west, between the Surma valley and Akyab, there are but few surface oil shows although numbers of occurrences of natural gas are known, especially about Chittagong. In the islands of Baronga, Ramree and Cheduba, both oil and gas seepages are fairly common. Submarine eruptions, sometimes of a very violent character, which occur from time to time off the Arakan coast, indicate the continuation of the petro-liferous rocks below the waters of this part of the Bay of Bengal.

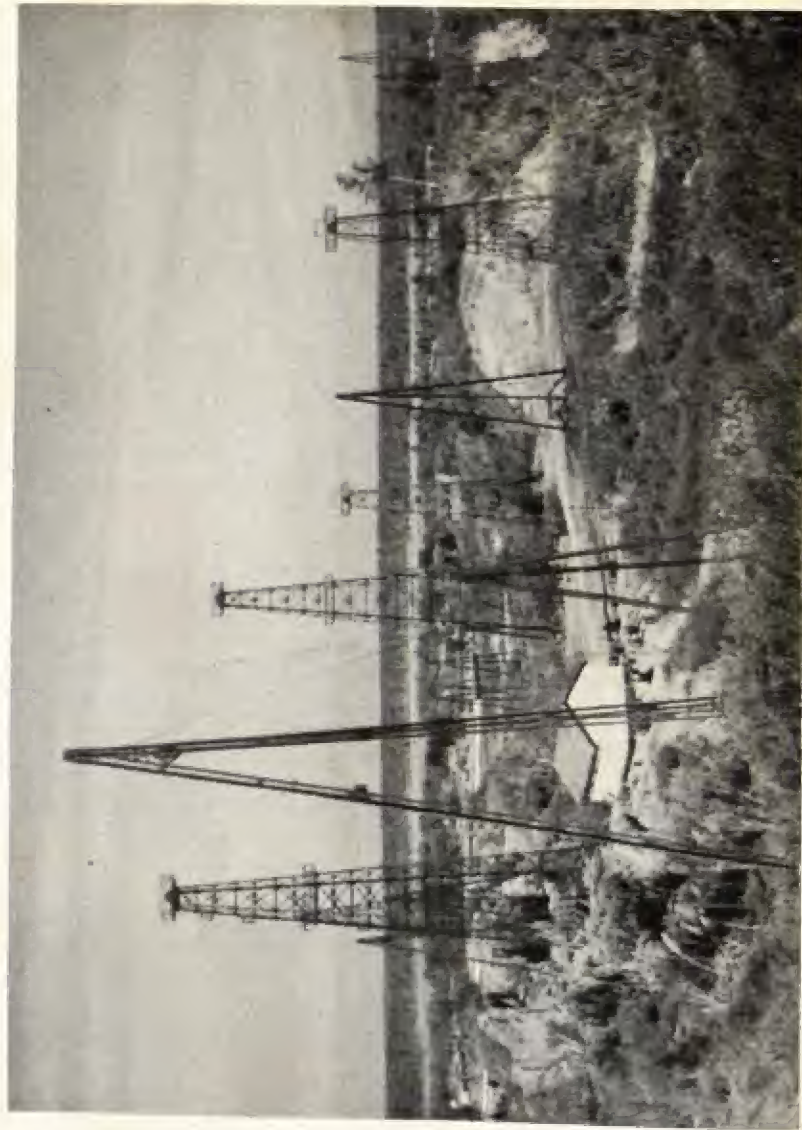
Much activity has been displayed in the search for oil-bearing structures in Assam and in the exploration of suitable ones by the drill, but the only areas which have yielded oil in commercial quantities are Digboi, in the Lakhimpur district of Upper Assam, and Badarpur, in the Surma valley, although small amounts have

been found in the Makum-Namdang area of Lakhimpur and at Masimpur and Patharia in the Surma valley.

Early Drilling near Jaipur and Makum. Oil drilling commenced in Assam in 1866 when four shallow wells, under 200 feet deep, were bored close to an oil seepage in the Coal Measures (the uppermost part of the Barail Series in Upper Assam), 3 or 4 miles south-east of Jaipur. In 1867, three more shallow bores were made in rocks of the same age, near gas and oil seepages close to Makum, and small quantities of oil were obtained. Nothing more appears to have been attempted until 1884, when the rights of the first lessees passed to the Assam Railways and Trading Company, a concern which bored several more holes at Makum between 1888 and 1895. These were mostly about 500 feet deep, though one well attained a depth of over 1,000 feet and obtained sufficient oil to warrant the erection of a small refinery. It is now known that the oilsands at Makum, within the reach of the drilling methods of those early days, all crop out at the surface. The wells were short-lived, the prospects of increased output at any attainable depth were poor and attention was accordingly directed to Digboi.

Digboi. Drilling commenced at Digboi in 1888, but it was not until 1892 that production commenced on the field. In 1899 its control passed to the Assam Oil Co. Ltd, and at the beginning of the century output was still under one million gallons per annum. Over the years it slowly increased, and twenty years later was being steadily maintained at about 5 million gallons annually. In 1921, the Burmah Oil Co. assumed technical control and in the next decade remarkable progress was made; by 1931, an output of over 53 million gallons had been reached, by 1936 this had increased to almost 65 millions; in 1944, over 82½ million gallons were obtained, and the annual average production for the five years ending 1950 was 65,521,230 gallons. From 1892 to 1950 inclusive, a total of some 1,558 million gallons of oil have been taken from the Digboi field. The crude oil is more or less saturated with solid paraffins of high melting point and it also contains considerable quantities of petrol; distilled in a refinery near the field, among its products are motor spirit, kerosene, jute batching oil, gas oil (high-speed Diesel oil), industrial Diesel oil, tea drier oil, furnace fuel oil, wax, lubricating oils and bitumen. To conserve the oil resources, as little gas as possible is produced, and any gas remaining after the fuel requirements of both field and refinery are satisfied is returned underground. As a final product the refinery produces about 1,200 tons of petroleum coke per month. Digboi itself is in the Lakhimpur district, 16 miles north-east of Jaipur and about 7 miles north of Margherita.

Forty years ago, the oil-bearing area of the Digboi field was only known to cover an area of about 130 acres, about ¼ of a mile long



WESTERN PART OF DIGBOI OILFIELD, ASSAM

Assam Oil Co. Ltd.

and $\frac{1}{2}$ mile broad, and, in the words of Sir Edwin Pascoe, it was believed to lie 'on an anticlinal dome in all probability asymmetrical or overfolded towards the north-north-west'. Since then, according to E. V. Corps, its limits have been enormously extended along the strike of the fold, with resumption of production after the intervention of barren patches of ground, according to the interplay between the structure and the texture of the reservoir beds. It is now known to be a faulted anticline, the thrust underlying the whole structure possessing a high hade, so that although an anticlinal arch is apparent at the surface, at some distance down the thrust fault cuts across the axis of the fold, to run almost parallel to the beds on the southern flank. This feature sets definite limits to the downward extension of the oil pools and to the profitable limits of boring across the width of the fold itself. Thus, though a deep test at Digboi in 1931 revealed new oilsands below those then being drained, the thickness of the new group was curtailed by the occurrence of the overthrust at an unexpectedly shallow depth. Meanwhile, in 1930 a deep well in the Hansapung part of the field proved a large eastward extension of the deeper oil pools; later on additional extensions were discovered, especially by exploratory wells drilled during the war, when the output of Digboi was increased to meet the increased demands for petroleum products. Subsequently, further exploratory drilling both to the west and the east of the proved part of the field was disappointing, but between 1948 and 1952 several wells drilled still farther east have revealed the presence of useful additions to the reserves of this oilfield.

When Sir Edwin Pascoe was writing of Digboi in 1912, it was naturally supposed that the oil-bearing beds of the Digboi wells and the oilsands cropping out in the centre of the anticline could be correlated with the oil-bearing Coal Measures (Barails) of Jaipur and Makum. Later geological investigation has shown, however, that the oilsands of Digboi are in the Tipam Sandstone, which is the lower member of the Tipam Series, and that they are accordingly of approximately Middle Miocene age.

Badarpur. The oil seepages which occur near Badarpur, in the Cachar district, led to drilling by the Badarpur Tea Company and the registration of the Badarpur Oil Syndicate in 1912. In 1915 it was announced that the Syndicate had made an agreement with the Burmah Oil Co. Ltd. As described by G. W. Lepper, the field occupies a small dome with a steep, faulted, eastern flank, about a mile long with a maximum width of a quarter of a mile. Output commenced in 1917, reached a maximum of over 8 million gallons in 1920, dropped rapidly to half that amount, and gradually decreased to 55,867 gallons in 1933, when the field was abandoned after giving a total of 58,431,000 gallons. The oil was of a heavy, poor quality and accompanied by large quantities of water. In all 60 wells were drilled, but the decline in yield was rapid and was

usually accompanied by a great increase in the production of water. The main output came from sands down to 1,400 feet; those at lower levels proved to contain only very small amounts of oil. The outcropping beds belong to the lowest division of the Surma Series and the wells were drilled both into its rocks and into those of the underlying Barails.

Other Areas. Many efforts have been made to find new oilfields: in Upper Assam anticlinal structures, apparently suitable as far as surface indications were concerned, have proved on boring in one area after another to possess thrust faults of high enough hade to render them worthless. In the Surma valley, where such faulting is not so widespread, no success has yet attended the costly prospecting that has been carried out.

Ten miles to the east of Badarpur lies the Masimpur anticline, a closed structure of relatively large size with many gas and oil seepages. The Burmah Oil Co. drilled its first well here to a depth of 1,540 feet in 1918; since then over ninety shallow holes have been drilled for structural information, and in addition eight holes have been taken to between 1,000 and 4,000 feet, the deepest well reaching 7,685 feet in 1931. Further drilling was planned, but during the second world war all prospecting work both in Assam and elsewhere was discontinued at the request of the Government of India, in order that the available effort could be concentrated on the known producing fields. Very difficult technical problems have been encountered at Masimpur, and although a few shows gave, over a period of several years, a small amount of oil (little more than 50,000 gallons all told) no commercial production has yet been proved. The sequence of test wells and bore holes drilled for structural information has cost about $1\frac{1}{2}$ crores of rupees and yet the anticline cannot be considered as finally proved and found wanting. Its example is quoted in detail here to illustrate the time, trouble and expenditure needed in the search for a new oilfield.

South of Badarpur, test wells on the Kanchanpur and Chhatachura anticlines have found no paying production. The Patharia Hills anticline on the south-eastern edge of a wide alluvial area in the Surma valley is a very pinched fold with almost vertical dips on each flank. In the crestal area the fold is asymmetrical with a steeply dipping and faulted western flank. Three wells have been drilled, the deepest reaching 5,411 feet, but the only oil produced was less than 250,000 gallons obtained at intervals about twenty years ago from the first well drilled. This anticline lies on the boundary between Assam and East Pakistan, and the sites of these test wells are in Pakistan.

Geological prospecting, accompanied in some cases by geophysical work, and in many instances taking advantage of the aid offered by aerial photography, has covered all the remaining more accessible parts of Assam but without revealing promising

structures. This geological work has also extended into Tripura, where structural conditions are somewhat less unpromising, but so far it has not been possible to test any of the Tripura anticlines by the drill.

In Upper Assam, renewed attempts to obtain oil from the Makum-Namdang lease have been made from time to time, but after a sequence of failures, during which 18 wells were drilled in different parts of the structure to depths of from a few hundred feet to over 5,000 feet, it was concluded that commercial production was not obtainable. The few wells which gave any showing of oil at all had a very rapid decline in yield and the lease was relinquished in 1950.

South-west of Digboi, in the Jaipur anticline, attempts to find oil continued at frequent intervals from 1920 to 1946, but the wells were all complete failures. Farther south-west test wells at Bandersulia, Tiru Hills, Barsilla and Nichuguard, all in the hills on the south-east side of the Assam Valley, have also proved unsuccessful. The anticlinal structures tested are cut off by thrust faulting, and in the comparatively small thickness of beds above the fault (whether Tipam Series, Surma Series or Barails), no productive sands have been found.

Early in 1953, the Assam Oil Company struck an oil-bearing formation at Nahorkatiya, 18 miles west of Digboi. The geophysical survey of the area, interrupted by the second world war, was resumed in 1951 and the test drilling started in May 1952. This well, Nahorkatiya No. 1, the deepest yet drilled in India, began a daily production of 20,000 gallons of crude oil from a depth of 11,715 feet in March 1954. A second well had then reached a depth of over 7,000 feet and a site had been selected for a third well. The oil will be piped to the refinery at Digboi through an eight-inch line laid alongside the road connecting Nahorkatiya with the older field.

PROSPECTS FOR PETROLEUM IN OTHER PARTS OF INDIA

Practically the whole of Peninsular India and the greater part of the Himalayas can be ruled out in any search for oil. Various parties, including those of the Geological Survey of India, have investigated the possibilities in Kutch and Saurashtra and have concluded that they are not promising. There are indications of oil and gas in the foot-hills of Jammu, Kashmir, extending on the one hand to the small fields of the Punjab and on the other to link up with the Tertiary foot-hills of the East Punjab, north-western Uttar Pradesh and Nepal. Gas seepages are known to occur in the Kangra district of the Punjab and in Nepal, where age-long pilgrimages have been made to the sacred fires for which they are responsible. Sufficient is known of the geology of the Himalayan foot-hills generally, however, to show that their structure is almost

universally unsuitable for the accumulation of petroleum. At the same time, only large-scale geological surveys can show whether or not there may be some few areas where conditions are less unfavourable and which may accordingly be thought worth the final test of the drill.

A few gas seepages have been reported from the eastern coastal tracts of the Peninsula, in areas where rock exposures are not plentiful, and it is probable that the gas is marsh gas originating in the alluvium and having no connexion whatsoever with petroleum (see NATURAL GAS). As the thickness of marine sediments in the areas concerned is believed to be only small and as there is no evidence of well-marked folding, the prospects have not appeared sufficient to petroleum geologists to warrant either detailed geological mapping or geophysical surveys. In the western coastal strip, the limitation of marine sediments to a very small area also renders them unattractive.

Much of the large alluvial area of the Brahmaputra and Ganga has been surveyed by geophysical means; gravity surveys have been used for covering large tracts, and seismic surveys have been carried out in certain selected smaller areas; in West Bengal a magnetometric survey was made during 1951-2. Taken as a whole, the results of the geophysical work on the alluvial areas is reported to have been extremely disappointing.

CONDITIONS IN EAST PAKISTAN

A few oil and gas shows have been recorded from the south-eastern part of East Pakistan (the Sylhet and Chittagong districts and the Chittagong Hill Tracts) but so far no oilfield has been found. The unsuccessful drilling at Patharia, on the boundary between the Sylhet district and Assam, has already been referred to. Near Chittagong a well-known gas show occurs on the Sitakund anticline, but drilling there about forty years ago failed to find oil and later structure drilling has revealed the complexities of the overthrusting on the western flank of this anticline. A test well on the neighbouring Patiya anticline was begun in 1952. Farther north, structure drilling and gravity surveys have been carried out near Sylhet, and a large part of the alluvial area of the Surma valley and the Ganga-Brahmaputra delta has been covered by geophysical prospecting, either by gravity or magnetic measurements.

In the preparation of these short accounts of the oilfields of Burma, East Pakistan and Assam, the authors have had the great advantage of the help and friendly criticism of Mr P. Evans, Chief Geologist of the Burmah Oil Co. Ltd. They also wish to express their gratitude to Mr E. S. Pinfold, Chief Geologist of the Attock Oil Co. Ltd, for the following authoritative account of the oilfields of West Pakistan which is reproduced here in his own words.

OIL-BEARING REGIONS OF WEST PAKISTAN

by

E. S. Pinfold, M.A., F.G.S.

Oil and bitumen have been known and used in West Pakistan from the beginnings of civilization; bitumen, probably from Baluchistan, was used as mortar in some of the buildings of Harappa and Mohenjodaro. The first attempt to develop oil production was made in 1870 when an American oil expert was invited by the Government of that time to report on oil prospects and to recommend a testing programme. There was a renewal of the search in 1890 and a little oil was obtained from shallow wells drilled near Jaba in the western Salt Range and at Chharat to the south of the Kala Chitta Hills; small amounts of this oil were utilized in the gas-works of Rawalpindi for many years.

The oil occurs in a narrow belt of Tertiary rocks in the outer foot-hills of the Himalayan, Baluchistan and Sind mountain ranges and the belt continues along the Makran coast into Iran. Oil seepages are numerous in the Rawalpindi, Attock, Jhelum and Shahpur districts to the east of the Indus, and in the Kohat, Dera Ismail Khan, Dera Ghazi Khan and Sibi districts across the river. No oil seepages are known in Lower Sind, but natural gas is evolved at several places: in Las Bela State and in the Makran, the flows of mud associated with some of the gas shows form mud volcanoes, and those at Chandragup at the mouth of the Hingol River are amongst the largest known.

Most of the region in which the oil shows occur was mapped by A. B. Wynne of the Geological Survey of India about the middle of the last century, and some of the anticlinal structures on which oilfields have since been found are clearly indicated on his maps.

With few exceptions, the oil and gas shows of West Pakistan occur in rocks of Middle or Lower Eocene age and these rocks are mostly marine sediments with some intercalations of beds laid down in fresh or brackish water conditions. The rock-salt deposits of the Kohat salt region are of Middle Eocene age and are closely associated with the oil seepages of that district. It is possible that the alternation of marine and brackish water conditions was responsible in part for the formation of the oil from the remains of marine organisms.

These Eocene beds are overlain with pronounced unconformity by a series of freshwater sandstones and shales, several thousands of feet in thickness, of Miocene, Pliocene and Pleistocene age, known as the Murrec-Siwalik System. This formation is highly fossiliferous and has yielded a continuous record of terrestrial vertebrate life over these periods.

Finally, during the uplift of the Himalayan and associated mountain ranges, the region was subjected to compression and earth movement resulting in fold structures, some of which have

served as areas of accumulation and reservoirs for oil, but the more favourable and open folds occur only in the outer foot-hills zone. Although seepages are numerous further into the hills, the folding there is usually too intense and the folds themselves too compressed or broken to hold useful oilfields—several test wells have been drilled near seepages in the closely folded foot-hills without successful results.

The four oilfields so far discovered are near the centre of the Potwar Plateau which lies between the Kala Chitta and Khaire Murat hill ranges on the north and the Salt Range on the south. Structurally the Potwar is a large synclinal basin occupied by a great thickness of Siwalik rocks. The principal axis of the basin coincides nearly with the valley of the Soan river and is known as the Soan syncline. The synclinal structure is interrupted on both flanks by strike faults and anticlinal folds, and it is on some of these anticlines that productive oilfields have been developed. In the order of their discovery these fields are Khaur, Dhulian, Joya Mair and Balkassar.

The Khaur and Dhulian dome structures are arranged *en echelon* along the first anticlinal fold north of the main syncline and parallel with it. The Joya Mair and Balkassar folds are interruptions to the south flank of the Soan Basin about twenty-five miles south of Khaur and Dhulian.

Khaur. The Khaur oilfield was discovered in 1915.¹ It occupies the summit of a long narrow anticline, the crest maximum of which lies 44 miles south-west of Rawalpindi. Murree rocks form an ellipse in the axis of the fold and are surrounded by ridges of Lower Siwalik sandstones. The crest of the fold is open, but dips steepen rapidly to 35° on the south flank and to 60° and 70° on the north. A strike fault runs parallel and close to the crest; this, like all other important faults of the region, is an overthrust, the north flank of the anticline overriding towards the crest.

The Khaur field differs from the others in that most of the oil produced from it has been from the freshwater sands of the Murree Series; production has been found in all the sands from the surface down to the Eocene limestones at over 5,000 feet. The oil is believed to have had its origin in these limestones and to have reached the overlying sandstones by migration. It has been suggested that migration took place along fault planes, but no close relation between faulting and oil occurrence has been recognized. On the other hand, there is no doubt but that the oil is contained in the fissures of the sandstones, and fissuring of both sandstone and shale beds may have played a major role in the upward migration of the oil.

Owing to the 1914-18 war, the pipeline to Rawalpindi and the refinery erected there were not completed until 1922, and it was

¹ The recognition that the Khaur anticline was a potential oilfield is due to the work of Mr Pinfold himself. J.C.B.

only then that the productive capacity of the field could be tested. Results were somewhat disappointing, for the production of a large number of shallow wells fell off very rapidly due to the drainage of the fissure system in each sand. The highly saline water which later accompanied the oil was under moderate to high pressure, and oil and water flowed at the surface during the early life of the field. New sands were tapped as drilling was carried to greater depths and each new sand caused a revival of production, though usually followed by a rapid decline.

Drilling to the Eocene limestones at over 5,000 feet proved extremely difficult and hazardous owing to the excessively high pressures (over 6,000 pounds per square inch) in the lower formations and the consequent heaving of the shale beds above the limestones. Some production has been obtained from the Eocene but not in the amounts hoped for, and it seems clear that much of the oil originally in the limestones has been lost by migration to the overlying Murree rocks.

Owing to the failure to obtain fresh production, the output of the field has now declined to a few barrels daily from a number of stripper wells. Its total production from the commencement of work in 1915 to date (October 1952) has been a little over 160 million gallons.

Recently another well has been drilled to the limestones, but its successful completion has been prevented by pressure troubles and heaving formations. A well formerly carried down some distance into the limestones struck heavy flows of brine containing much sulphuretted hydrogen.

Dhulian. The Dhulian field is on a more open dome structure eleven miles south-south-west of Khaur. It forms part of the same general uplift, with its axis parallel to the Khaur axis though aligned two miles to the south of it. Its gentler folding is reflected in the wide crestal ellipse of low dipping rocks; the outer flank dips being about 35° on the south and 30° on the north. There is a low westerly pitch as the fold merges into the Soan syncline.

The Dhulian crest is at a much higher stratigraphic level and is in Lower Siwalik rocks which causes the Eocene to lie approximately 2,000 feet deeper than at Khaur. All the light crude oil is contained in the Eocene limestones at depths of from 7,650 to over 8,000 feet. The Murree rocks a short distance above the Eocene have given a small production of a heavy crude known as 'black oil' which is thought to be seepage oil of Murree times. The absence of light crude from the Murree rocks, in contrast with the conditions at Khaur, may be due to reduced fissuring in the more open fold. A strike fault runs near the crest at the surface but fades northwards so that if it cuts the limestones, this must be north of the productive area. Another fault has been observed in the limestones in one well on the south-eastern edge of the field.

It was recognized from the outset that the Dhulian structure was a possible oilfield, and testing began shortly after the Khaur field reached its full development. The early drilling was done by cable tools and the first four wells had to be abandoned one after the other because of high-pressure water flows from the Siwalik and Murree sands. The fifth well was drilled by the rotary system and reached the Eocene in 1935. A good show of oil was obtained, but this well proved to be at the eastern edge of the field and production was therefore short-lived. In 1937, No. 7 well, known as the Coronation Well, came in as a large producer of high-grade oil.

The field was linked by pipeline with Khaur and Rawalpindi and production from Dhulian proved a valuable supplement to the declining production at Khaur. The field was operated at a high rate during the war years, and this may have hastened the appearance of salt water with the oil and caused a sharp decline of output from 1942 onwards. The total production of Dhulian from this level to date (October 1952) has been over 213 million gallons.

Recently, following small shows of oil at lower horizons in other fields, a well was carried down to test for deeper oil. A new productive zone was found in the Lower Eocene (Ranikot) limestone. This, like the upper horizon originally, is under very high reservoir pressure. Another well has obtained similar results and others are being taken in hand to deepen and so to test the size of the new oil pool.

Drilling difficulties at Dhulian have been much less than at Khaur, though large flows of very hot water under considerable pressure have to be drilled through and cemented off behind casing.

Unsuccessful test wells were drilled by the Attock Oil Company at Chharat, Ganda Kas and Bokra, in the northern foot-hills east of the Indus; at Chorlakki in the north-eastern corner of the Kohat district; and at Babai and Dalwatti on the Marwat Range on the eastern border of the Bannu district. Other unsuccessful tests were drilled by the Burmah Oil Company at Meyal, fifteen miles north-west of Dhulian, and at Khabakki on the Salt Range; another failure was drilled by the Whitehall Corporation at Jhatla, thirty miles south of Dhulian. The Attock Oil Company also drilled a test at Jhatla with negative results.

Notwithstanding these disappointments, prospecting was renewed with even greater activity during the later years of the war. Another test was made of the Meyal structure, this time by the Attock Oil Company, and one of the test wells was carried to over 10,000 feet but no show of oil was obtained. Another failure had to be recorded at Uchhri, thirty miles further to the north-west, where a test was abandoned at over 9,000 feet. Two structures in the south part of the Potwar were tested and these tests proved successful; these are now the oilfields of Joya Mair and Balkassar, 25 miles south-east of the Khaur and Dhulian fields.

Joya Mair. The Joya Mair structure was described as suitable for the retention of an oil pool by Dr D. N. Wadia, in the Records of the Geological Survey of India for 1929. He pointed out that, although the crest of the fold is tightly compressed at the surface, the flank dips are low and the fold might be expected to be more open at depth. All this received striking confirmation when the first well, put down in 1945, encountered oil at 6,900 feet in Eocene limestones dipping at only moderate angles. On a short test the well flowed at the rate of several thousand barrels daily (one barrel is equal to 40 Imperial gallons). The oil, however, is quite different in character from that of the Khaur and Dhulian fields, in that it is a very heavy (S.G.=0.950) black crude containing nearly 70 per cent asphalt. It is unique in that the middle fractions, the lubricating oils, are absent. Although quite fluid under reservoir conditions of high pressure and high temperature, the oil when exposed at the surface loses its dissolved gas and lighter fractions and becomes solid asphalt in the course of a few days.

Two wells have been drilled to the oil zone and are now in production.¹ A third well drilled further down the southern flank of the structure failed to get oil in the Eocene and was deepened to test lower formations. It penetrated Carboniferous and Cambrian rocks and ended, owing to mechanical difficulties, at 8,820 feet in the Saline Series of the Salt Range sequence. An unsuccessful deep test was drilled by the Burmah Oil Company on the northern flank of the Joya Mair structure.

The Joya Mair oil is transported to the Rawalpindi refinery in tank wagons fitted with special heating arrangements. It is refined in a separate plant, the main product being bitumen.

Balkassar. The Balkassar structure is situated ten miles west of Joya Mair, these two folds having much the same relations to each other as the Khaur and Dhulian folds. The surface crest at Balkassar is at a higher horizon than that at Joya Mair, though the steep dips in the higher part of the Joya Mair cross-section add to the depth to be drilled there and so lessen the differences in depth which would otherwise have occurred. The structure at Balkassar is very open, the dip in the limestones being only 1° to 3°. A belt of comparatively steep dips lies along the north-western flank of the structure. Due to the northerly thickening of the Murree-Siwalik formations, the crest maximum at depth lies about two miles to the south of its position at the surface.

The first well drilled by the Attock Oil Company in 1946 reached the Eocene limestones at 8,135 feet, and shows of oil were obtained in the Bhadrar beds, dolomites, limestones and shales, which lie above the main Nummulitic limestone, known as the Sakesar Limestone. The well was deepened and found flowing

¹ Production in 1948 was 6,831,920 gallons.

" " 1949 " 5,991,920 " "

production in this Sakesar Limestone, and it is from it that most of the 140 million gallons of oil obtained to date have been won. In 1951, a well drilled some distance north of the earlier wells got good production from the Bhadrar beds themselves.

The Burmah Oil Company obtained production from a well drilled south of the Attock Oil Company's lease, and the field is at present being worked as a unit by the two companies. A peculiarity about the Balkassar field is that, whereas in the three older fields the oil occurs in the highest part of the structure, at Balkassar the productive area is asymmetrically disposed, good wells being obtained on the northern flank of the fold, whilst wells further south have so far proved disappointing.

Prospecting work continues actively, though now by new subsidiary companies formed in accordance with the Rules and Regulations of the Mines Department of the Government of Pakistan. The Pakistan Oilfields Limited was formed to take over the prospecting rights of the Attock Oil Company. This company is at present (1952) drilling a deep test at Bains, thirty miles south-south-east of Rawalpindi, as well as a number of shallow structure tests at Karsal, four miles north of the Balkassar field, and at Dhariala in the centre of the Salt Range Plateau.

Pakistan Petroleum Limited was formed to take over the Burmah Oil Company's licensed areas and is drilling a deep test at Chak Naurang, ten miles east of the Joya Mair field, in addition to further wells in the southern part of Balkassar. Deep testing is also in progress in the Bugti Hills of Baluchistan.

In the course of this work a large field of natural gas has been discovered at Sui, 60 miles north-north-east of Sukkur. The structure is an open dome in Siwalik rocks, the gas occurring in the underlying Eocene. Although the extent of the field is yet unknown, gas has been proved in two wells five miles apart and it is believed that the deposit will be capable of supplying West Pakistan's fuel requirements for many years. (See NATURAL GAS.)

The deepest well yet drilled in Pakistan was at Lakhra in Lower Sind, and this test had to be abandoned at 12,666 feet when hot salt water was encountered under extremely high pressure and could not be controlled. Other test wells drilled earlier in or near Sind were at Khairpur, Drigh Road near Karachi and, in 1916, at Chandragup in Las Bela.

It is natural that the search for oil becomes increasingly difficult as more and more of the apparently favourable areas are tested. Every scientific aid is being used in the task, including air photography and all branches of geophysical prospecting. The search for oil demands not only scientific and technical skill, but also large capital resources. The amount expended in oil prospecting

in Pakistan to date amounts to many crores of rupees, but still the search goes on.

PROSPECTS FOR THE FUTURE IN PAKISTAN

The general outlook for petroleum prospecting in West Pakistan has been ably summarized by Dr D. N. Wadia, who outlines the region concerned as the broad zone of Eocene-Miocene sediments which stretches from Lower Sind to the north-eastern Punjab, passing through Baluchistan and the North-West Frontier Province and thence, after crossing the Indus between Kalabagh and Kohat, continues along the foot-hills of Jammu to Kangra. Surface indications of both oil and gas are known at many places in it, some localities have been tested, others have been examined, many but superficially, others in greater detail, but great tracts of the region still await methodical investigation by petroleum geologists: indeed, the most widely spread expanse of Lower Tertiary rocks ranging from the Makran to Karachi and thence northwards to Kohat, in which the sinuous, folded, surface exposures have a width of from 100 to 250 miles, remains for the most part unexplored from this point of view. Shallow wells drilled at Khattian, in the Marri Territory, between 1884 and 1896, yielded 837,825 gallons of crude oil, but from that time onwards until the recent test in the Bugti Hills, mentioned by Mr Pinfold, no drilling has been carried out in eastern Baluchistan.

In the Kohat salt-bearing region, according to Dr E. R. Gee, 'the rock salt at several places contains traces of oil and it is not improbable that it forms a cap-rock overlying in places petroliferous limestones and shales of Lower Eocene age'. The Tertiary strata of the Potwar, from the Kala Chitta ranges in the north to the northern slopes of the Salt Range in the south, represent a broadening out and simplification of the compressed and complex structures of Kohat. Writing of the Soan Basin as a whole, Dr Wadia has given his opinion that 'more drilling and extensive search for structures, with the aid of geophysical means can be confidently expected to produce a few commercially productive fields in this part of the north-west Punjab'.

The Eocene and higher Tertiary rocks of the Dera Ghazi Khan district in the south-west of the Punjab are in direct continuation with those of the Bugti area of eastern Baluchistan, and suitable structures, if found either in the foot-hills or beneath the alluvium of this region, should afford favourable conditions for the accumulation of oil pools. Further north, in the Sherani country of the North-West Frontier Province, the oil seepages of the Takht-i-Sulaiman Range, near Moghal Kot, have been known for more than 110 years.

From the North-West Frontier district of Hazara, the Tertiary rocks continue along the foot-hills of the Himalayas to the

Sadiya Frontier Tract of Assam, except for a small break near Darjeeling. The geological history of this zone and the structural deformations it has undergone during the course of that history, combine together to make the chances of the occurrence of profitable petroliferous deposits within it extremely problematical.

It remains to mention that Lower Tertiary rocks are believed to underlie the recent deposits which stretch eastwards from the foot-hills of Sind, Baluchistan and the southern Punjab up to and beyond the Indus, but the location of structures under the thick alluvial blanket demands geophysical prospecting of a highly specialized kind. The abandonment of the test in such an area, at Lakhra, in the Dadu district of Lower Sind, 125 miles from Karachi, after it had reached a depth of 12,666 feet in January 1950, has already been referred to by Mr Pinfold.

The search for new oilfields in Pakistan will continue but it can only be scientifically prosecuted by organizations, as Mr Pinfold has already stated, having at their command not only skilled geological advisers and experienced technicians but also large capital resources.

THE TRADE IN PETROLEUM AND ITS PRODUCTS

The production of petroleum in the former Indian Empire increased from an annual average of about 58 million gallons, worth less than a quarter of a million pounds sterling, at the beginning of the century, to one of 336,145,426 gallons, valued at £4,871,565, over the pre-war period 1934-8. To this amount Burma contributed 77.9, Assam 19.6 and the Punjab 2.5 per cent. The highest output was reached in 1938, with a production of 350,905,636 gallons, or roughly 1,381,000 tons, but as the world's total output of crude oil for that year was some 267 million tons, it is evident from a global point of view that the contribution of the Burmese and Indian fields is insignificant; indeed, for many years their combined output has consistently represented much below 1 per cent of the world's total. Yet to the regions concerned, these oilfields are of great importance.

The separation of Burma from India took place on 1 April 1937, and this event together with the overrunning of the country by the Japanese armies in 1942, the separation of Pakistan from India on 15 August 1947, and the general results of the second world war, have had far-reaching consequences for the oil business of the subcontinent. For the three years ending 1936, that is for the last pre-war period during which the Indian Empire existed as a single unit, India, which at that time included both Burma and Pakistan, consumed an annual average of 468,325,000 gallons of oil products, made up of kerosene, 46 per cent; fuel oil, 28 per cent; petrol, 19 per cent and lubricating and batching oils, 7 per cent. Over half of this amount (55 per cent) was made in her own

refineries from home-produced crude oil, the remainder, consisting for the most part of kerosene (30 per cent) and fuel oil (60 per cent), being imported from abroad. The kerosene came from Russia, 67·5 per cent; Sumatra, 11·7 per cent; Iran, 10·7 per cent and Rumania, 5·2 per cent, with smaller quantities from Borneo, Java, the United States of America and elsewhere. Of the fuel oil 74·7 per cent was brought from Iran, 21·4 per cent from Borneo and the rest from other countries. Thus, for the 192½ million gallons of kerosene which undivided India required in addition to her own manufactures, she depended mainly on the Soviet Republics, Sumatra and Iran, while three-quarters of the imports of fuel oil, amounting to more than 375 million gallons, were derived from Iran.

Turning now to the three post-war years 1948 to 1950, although exact figures are not obtainable at the time of writing, the average annual consumption of oil products for India alone, that is to say without either Pakistan or Burma, was approximately 728 million gallons, an increase of more than 56 per cent over the consumption of the whole of the former Indian Empire in 1934-6. The rate of increase was a rapidly progressive one between 1948 and 1950, and if the consumption for 1950 alone is taken—850 million gallons—the increase over the earlier period of 1934-6 becomes over 81 per cent. There is, however, one most noteworthy difference to be observed: whereas in the pre-war period India supplied 55 per cent of her own oil requirements, this proportion dropped to under 10 per cent and was but 7 per cent in 1949, partly owing to her loss of the oilfields of Burma and Pakistan and partly to the big increase in consumption.

Imported oil products averaged some 685 million gallons per annum during 1948-50, of which fuel oil accounted for 42·5 per cent, kerosene 27 per cent, petrol 23·5 per cent and lubricating and batching oils 7 per cent. Great changes have also to be noted in the sources of these foreign oils: of the kerosene supplies in 1948 and 1949, 68·5 per cent came from Iran and 20 per cent from Bahrein Island in the Persian Gulf, while the same two regions contributed no less than 90 per cent of the petrol and 83 per cent of the imports of fuel oil. The lubricating and batching oils were bought as to 66 per cent of the total from the United States of America, followed by Iran with 24 per cent and the United Kingdom with 8·5 per cent.

Even before the separation of Burma and Pakistan oil exports of Indian origin had become insignificant, but the exports of paraffin wax were a most important article of commerce, averaging 48,014 tons, valued at Rs 2,01,00,886, over the three years 1934-8. Indian wax of this kind had a very wide distribution to most of the countries of the Commonwealth, to many parts of Europe, to both North and South America and to various Asiatic lands. Like the crude oils from most of the Burmese fields, the oils of the Digboi

oilfield in Assam contain a high proportion of paraffin wax which still continues to be exported from this source of supply, the average quantity sent abroad from Indian ports for the two years 1948 and 1949 being 12,538 tons, valued at Rs 1,29,56,486; but about half of the Assam wax is exported through Chittagong in East Pakistan, the total average exports from Assam for the two years in question being about 25,000 tons.

The importation of oil products into India is increasing rapidly, their total cost rising from Rs 29 crores in 1948 to Rs 51 crores in 1949 and Rs 54 crores in 1950. No further argument is needed to strengthen the case for an intensified campaign of oil prospecting, particularly in Assam, to locate new structures as well as to investigate again some of the known ones, in the hope that new locations may yield production on anticlines already tested with negative results. India's dependence on imported fuels could be reduced to some extent by the manufacture of petrol from suitable coals of Bihar and elsewhere, a subject which is now under consideration.

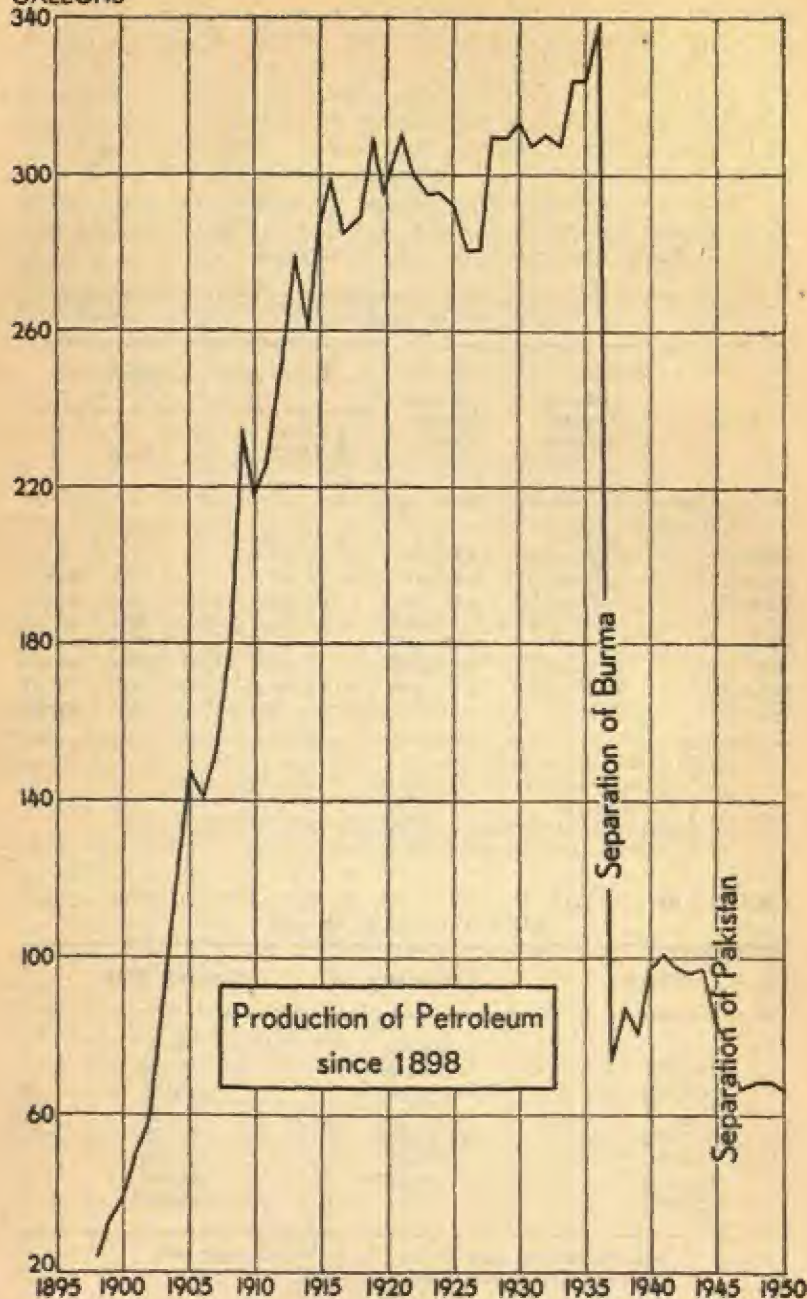
As a result of discussions which took place in November and December 1951 between the Government of India and the Burmah-Shell group of companies and the Standard Vacuum Oil Company, agreement was reached on schemes under which two modern oil refineries would be erected near Bombay for the refining of imported Middle East crude oil. These refineries would be owned and operated by Indian companies and financed partly with Indian capital; the capacity of the Burmah-Shell group refinery would be 2 million tons and that of the Standard Vacuum refinery $1\frac{1}{2}$ million tons per annum. The Burmah-Shell scheme, it is stated, should lead to the investment in the oil-refining industry in India of about Rs 20 crores (one crore of rupees being equal to about £750,000) of sterling capital. The share of the Burmah Oil Co. Ltd in the

AVERAGE ANNUAL PRODUCTION OF PETROLEUM IN INDIA,
1900-38

PERIOD	AVERAGE ANNUAL PRODUCTION	AVERAGE ANNUAL VALUE	PROPORTION YIELDED BY		
			BURMA	ASSAM	PUNJAB
	gallons	£	%	%	%
1900-3	38,067,771	231,319*	97.6	2.4	..
1904-8	146,506,989	592,887*	98.0	2.0	..
1909-13	240,187,714	928,072*	98.2	1.8	..
1914-18	282,594,121	1,134,916*	97.4	2.5	0.1
1919-23	299,453,675	7,036,298	95.0	3.7	1.3
1924-8	290,321,036	6,268,229	88.9	7.7	3.4
1929-33	307,362,400	4,319,280	81.4	15.8	2.8
1934-8	336,145,420	4,871,565	77.9	19.6	2.5

* Value stated to be greatly underestimated.

MILLION
GALLONS



provision of this capital is estimated at some £9 million. Another agreement following the general pattern of those of 1951 was signed in New Delhi on 28 March 1953. It provides for the establishment by the American Caltex Oil Company of a refinery at Visakhapatnam, Andhra, and involves an estimated expenditure of 15 million dollars. Desirable though these developments are, the greater part of the crude oil requirements of the new refineries will still have to be imported from abroad, unless and until new sources of supply are discovered in India, and it is to that imperative end that all available attention should be directed.

AVERAGE ANNUAL IMPORTS OF MINERAL OILS INTO INDIA
1900-38

PERIOD	AVERAGE ANNUAL IMPORTS	AVERAGE ANNUAL VALUE	PROPORTION BROUGHT FROM				
			RUSSIA	U.S.A.	BORNEO*	IRAN	OTHERS
	gallons	£	%	%	%	%	%
1900-3 ..	85,463,994	2,314,801	74.6	18.9	..	..	6.5
1904-8 ..	73,624,177	1,944,175	31.6	32.5	..	..	35.7
1909-13 ..	89,329,698	2,451,987	7.2	53.2	18.0	0.27	21.3†
1914-18 ..	89,747,579	2,748,990	0.4	54.8	23.3	9.2	12.3
1919-23 ..	117,241,203	5,514,977	..	40.0	19.2	32.4	8.4
1924-8 ..	194,518,757	6,999,856	..	34.8	17.0	38.2	10.0
1929-33† ..	226,315,287	7,164,512	11.0	15.7	14.1	41.7	17.5
1934-8‡ ..	236,340,516	4,431,120	14.3	0.5	17.7	45.0	22.5||

* Includes Sumatra.

† Includes imports into Burma up to March 1937 only.

‡ Fiscal years.

§ Described as kerosene and fuel oils only.

|| Includes 10.5 per cent from Burma.

AVERAGE ANNUAL EXPORTS OF INDIAN PETROLEUM AND
PARAFFIN WAX, 1904-38

PERIOD	PETROLEUM	PARAFFIN WAX
	gallons	tons
1904-8 ..	2,921,400	3,276
1909-13 ..	12,070,369	11,555
1914-18 ..	24,458,917	21,191
1919-23 ..	23,732,622	26,593
1924-8 ..	7,568,961	39,779
1929-33 ..	123,972	54,600
1934-8* ..	....	35,805†

* Includes exports from Burma up to March 1937 only.

† Valued at £1,128,729 or Rs 1,49,37,897.

OIL SHALES

Oil shales are shales or clays which on distillation yield petroleum of various grades, 'usually ranging', according to one authority, 'from asphalt or paraffin through heavy lubricating and fuel oils to the lighter illuminating oils, kerosene, and to petrol and the petrol ethers'. The shales themselves contain no free oil but abound in vegetable remains, spores, grains of wax and resin. 'The oil-producing constituents are yellow bodies of microscopic dimensions which have been identified as pollen grains, algae and spores.' Many of these are of a secondary nature formed by the redeposition of resinous and cellulosic material. The richer varieties of oil shale can be ignited with a match and burn freely; indeed, the use of oil shale for fuel by Karen villagers of the Burma-Thailand frontier first directed attention to the rich deposits of that region.

OIL SHALES OF LOWER BURMA

Amherst District. The oil shales of the Kawkaireik township, in the Amherst district of the Tenasserim division of Lower Burma, lie to the east of the Dawna range and close to the Thai frontier, indeed, two of the three basins in which they occur actually cross the border into Thailand. The deposits were described by Professor J. W. Gregory in 1923 and by G. de P. Cotter in 1924. Two of the areas are bisected by the Thaungyin river and, lying to the south and north of the frontier town of Myawaddy, are known as the Phalu and Mesauk-Methalaun-Melamat basins respectively, though it is possible that they join and form a continuous area across the frontier. The third is in the valley of the Mepale stream and derives its name from the village of Htichara.

The basins themselves are hollows in the older rocks which have been filled in by freshwater deposits of late Tertiary age, for the shales themselves contain the remains of fish and freshwater shells, together with the leaves of plants and ferns. They fall into two divisions, a lower one of sands and boulder beds and an upper one of shales with oil shales. In the Htichara basin, which is about 14 miles long and 9 miles broad, several quite rich seams of oil shale of varying thickness have been proved by boring to exist over a considerable area and down to a depth of 300 feet. The Mark Band seam is 6 to 7 feet thick and is stated to yield 15 to 20 per cent of crude oil. Five more seams containing smaller percentages of oil have been located above it. Samples of Htichara oil shale tested in the laboratories of the Geological Survey of India yielded between 9.78 and 16.20 gallons of crude oil per ton. The latter contained water, 13 per cent; light naphtha, 4 per cent; heavy naphtha, 3 per cent; kerosene 23 per cent; lubricating oil, 40 per cent; residue, 17 per cent. 'In the Htichara field', writes Cotter, 'there appears to be a good supply of shale of a rich or fair

average quality, so much in fact that it would be possible to obtain large quantities by open-casting.' Mining would be fairly simple; the strata dip gently, they appear to be fairly regular, the barren shales would form a good roof and floor, while the oil shales themselves would give solid, hard pillars. Originally bored by M. E. Moola and Sons Ltd, the Htichara deposits were afterwards leased to the Mepale (Burma) Oil Co. Ltd, and although an experimental retort was obtained for test distillations in 1932, large-scale exploitation had not commenced before the onset of the second world war.

OTHER OIL SHALE DEPOSITS

Oil shales have also been found in the Tertiary deposits which occupy the valley of the Theinkun stream, a branch of the Little Tenasserim river, in the Mergui district of Lower Burma, while other low-grade material is known to occur near Bonkun, in the Lenya valley of Mergui, and in that of the Great Tenasserim valley of the adjoining Tavoy district.

Low-grade oil shales have been noted by Cotter in association with the Salt Marl of the Punjab Salt Range, but they are not believed to possess any economic importance.

NATURAL GAS

Dissolved in the petroleum occurring in the pores of sands and limestones there is always some natural gas, consisting chiefly of methane, CH_4 , with smaller amounts of other hydrocarbons; in many fields natural gas also forms a 'gas cap' in the highest parts of the oil-bearing horizon. In the earliest days of the oil industry the importance of conserving this gas was not appreciated, but for many years past it has been realized that the pressure under which oil and gas exist in an underground sand, together with the amount of gas actually dissolved in the oil itself, are potent factors in the recovery of the oil, for it is in part the propulsive power of the gas, when the sand is tapped by the drill, which forces the oil to the well and helps to raise it there. Modern oilfield practice, therefore, permits as little of the gas to escape as possible, and aims at keeping the gas/oil ratio of the crude oil produced as low as circumstances permit. Gases escaping naturally, or pumped from oilsands, are also saturated with the vapours of highly volatile, liquid hydrocarbons in suspension which form a valuable source of gasoline when recovered in suitable plant. By 1931, over two million gallons of natural gasoline were being extracted annually from gases liberated on the Yenangyaung oilfield of Burma alone, and by 1939 installations on this and other fields in Burma were recovering such liquid hydrocarbons at the rate of over $11\frac{1}{2}$ million gallons per annum. The dry gas, stripped of its liquid contents, was used for fuel purposes and produced the electrical power which

supplied the major oilfields with their energy. Any remaining surplus gas was returned to the underground reservoirs whence it came, to perform more useful work in repressuring the depleted sands and in bringing another load of gasoline to the surface.

The gas of the Digboi oilfield in Assam is used both for fuel and for repressuring the oilsands. As E. V. Corps has recorded, great attention is paid there to the gas/oil ratio, the producing conditions being varied to reduce the gas/oil ratio to the minimum attainable; wells which give high gas/oil ratios are closed in and not produced from until it is found that the oil can be taken at an acceptable gas/oil ratio. In the case of the Punjab, the Balkassar oil is associated with very little gas.

Besides the gas found in association with oil and coming from the same sands, there are other sands in various fields which contain gas alone and it is usually methane in a dry condition. The natural gas resources of Burma were fully described in a memoir of the Geological Survey of India, by Dr C. T. Barber, published in 1935. Two cases only can be mentioned here to indicate how great these resources are. On the Indaw oilfield alone there was available at that time a quantity of 12 million cubic feet daily and it could doubtless have been increased if necessary. Several wells on the Indaw field had already been abandoned on account of high gas pressure. Well No. 1 had been delivering gas steadily for 15 years with a very slight decline in yield and pressure and seemed likely to do so for years to come. At the other end of Burma, in the Thayetmyo district, searching for oil a well liberated gas at a depth of 2,525 feet, in quantities estimated at 39 million cubic feet in 24 hours. After escaping for eight months, the flow was brought under control with only a slight diminution of pressure. The gas liberated in this case represented the thermal equivalent of an oil well producing 5,000 barrels per day and it is now used to supply a cement works with its fuel. (See CEMENT).

A natural gas field of great extent has been recently proved in the southern part of the Bugti Tribal Area of Baluchistan some 60 miles north-north-east of Sukkur, a town on the Indus in Sind. The large open dome of Tertiary rocks in which it occurs was delineated many years ago on maps published by the Geological Survey of India but until 1952 it laid untested, when a well drilled in search of oil by the Pakistan Petroleum Company tapped its gas reservoirs. A second well five miles distant from the first one confirmed that these are of vast extent.

The Sui Gas Transmission Company has been incorporated in Pakistan to lay a pipeline, 350 miles in length, between the field and Karachi, at an estimated cost of £9 million. By March 1954 much of the equity capital had already been provided by investors in Pakistan, the Commonwealth Development Finance Corporation, the Pakistan Industrial Development Corporation and the

Burmah Oil Company. The magnitude of this concern is a measure of the belief of its sponsors in the capacity and probable length of life of the field itself.

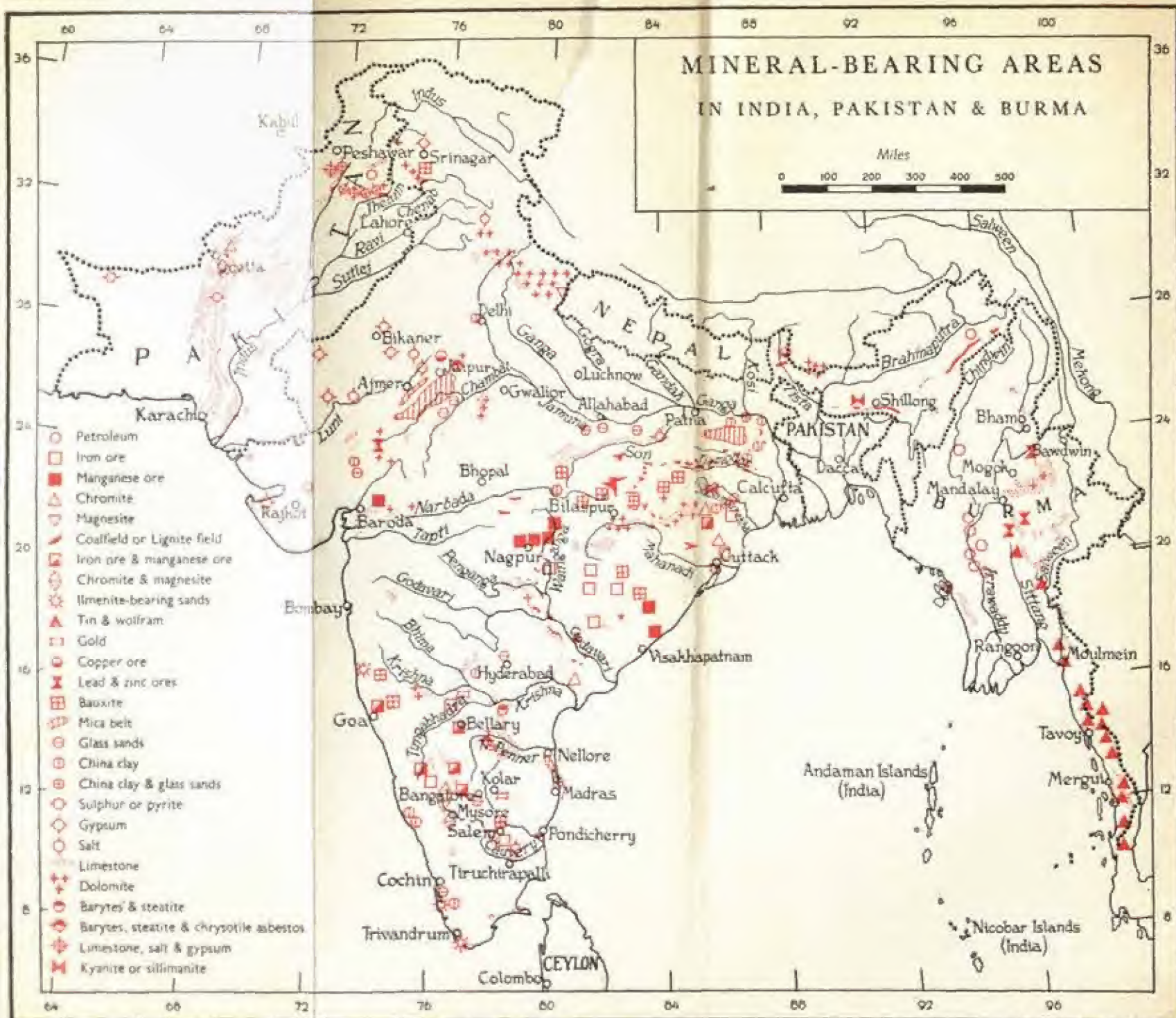
There are many possibilities in the chemical utilization of methane and its associated hydrocarbons as a starting-point in the synthesis of a host of organic chemicals, including dyestuffs, solvents and anaesthetics. In some countries the natural gases are piped for great distances to industrial centres for heating, domestic and power purposes; in the United States of America they have been found to carry small amounts of helium, a light, non-inflammable gas which is extracted on a commercial scale and used for filling airships and other purposes.

In India natural gas has been tapped at Jagatia and Gogha in Saurashtra and at Baroda. It is believed to be derived from Upper Tertiary strata which rest on an underlying platform of Deccan Trap and which thicken towards the Gulf of Cambay. Dr P. K. Ghosh states that the Gogha gas sand lies at a depth of 812 feet below the surface and is 35 feet thick. A sample of the Gogha natural gas, analysed by H. E. Watson, contained 0·8 per cent of helium. Further exploratory drilling is essential before any conclusions can be drawn as to the extent of this occurrence.

Natural gas in smaller quantities is sometimes met with in sinking tube-wells for water in alluvial districts, and such occurrences have been reported from Saharmul, in the Mymensingh district of East Bengal, and from Thetkala, in the Pegu district of Lower Burma. In these and similar instances, the marsh gas was probably formed by the decomposition of vegetable debris in the local deltaic deposits. Three or four other occurrences have recently come to the notice of the Geological Survey of India from deltaic, alluvial deposits in the East Godavari and Krishna districts of Andhra and the Tanjore district of Madras. Samples of the gas from Tatipaka, in the first-named, and from Neypattur, in the last-named district, contained 70·4 and 69·1 per cent of saturated hydrocarbons and 1·0 and 0·5 per cent of unsaturated hydrocarbons, respectively. It is important to observe that though gas supplies from such sources may serve as fuel on a small scale for heating or for gas engines, it is delusive to regard them as certain indications of the presence of underground supplies of petroleum.

PART II
THE METALS AND THEIR ORES





CHAPTER II

THE PRECIOUS METALS

GOLD

PLINY, in A.D. 77, referred to the country of the Narcae, now identified with the Nairs of Malabar, as containing many mines of gold and silver, and there can be no doubt that gold mining in India dates from prehistoric times. Owing to the absence of references in the medieval Mohammedan records, however, some authorities believe that the greatest activity took place before A.D. 1000. The occurrence of alluvial gold in the southern portion of the Malabar district has received attention from the year 1793 onwards, and in 1831 Nicholson discovered the remains of numerous old workings in the south-east Wynaad, the highlands which lie between the Nilgiri plateau and the low country of Malabar proper. The region was prospected from about 1875 onwards but, although occasional discoveries of very rich pockets were made, the results on the whole were very poor. In spite of this no fewer than 33 companies were floated between 1879 and 1881, with an aggregate capital of over £4,000,000. The total quantity of gold produced appears to have been about 600 oz. and mining operations ceased in 1893. Investigations by Sir Henry Hayden and Dr F. H. Hatch, in 1899, of the veins near Devala and Pandalur gave average gold contents of under 2 dwt to the ton.

A re-examination of the veins in the same neighbourhood, however, by Dr H. Crookshank of the Geological Survey of India, in 1939-40, led him to believe that though small they still merit further attention. The failure of the earlier ventures is, in his opinion, not to be attributed entirely to low-grade ore, for bad financial management, metallurgical troubles, the low price of gold, the lack of mining labour, and the difficulties usually associated with pioneer efforts in an isolated, malarious region, also contributed to the collapse of gold mining in the Wynaad. During the last war, a company known as Nilambur Mines Ltd commenced operations, primarily with the object of exploiting the auriferous pyrite of the veins as a source of sulphur, but the importation of supplies from the United States in 1944 frustrated the plan and left the Company with the problem of proving the reserves of a low-grade, refractory, gold-bearing ore.

An examination of the Alpha and Harewood mines of this company was made by D. Kerr-Cross, Mining Engineer to the

Geological Survey of India, in 1951, which showed that the ore on No. 9 level of the Alpha mine averages less than 2 per cent sulphur and 2 dwt of gold per ton. There are however, some payable sections, totalling about 13,000 tons, averaging 2.91 per cent sulphur and 2.85 dwt of gold per ton, which might be worked at a small profit. The bottom level (No. 11), where almost 1,000 feet of driving had been done, was not examined due to ground collapse near the adit entrance. In the Harewood mine, the lode is of limited extent along both strike and dip. There is one payable length of about 100 feet but this is not expected to persist far below the bottom No. 5 level.

The gold of southern India and of Chota Nagpur is derived from quartz veins which traverse the rocks of the Dharwar System, consisting principally of hornblende, chlorite and mica schists, argillites and phyllites, quartzites and quartz schists, boulder beds and pebbly conglomerates, together with epidiorites and other intrusive masses of dioritic and basaltic character. They are found in long, isolated, more or less parallel bands and outlying patches in the gneisses, granites and charnockites forming the main mass of the Archaean complex. The vein quartz occurs in two forms, either as a dark blue or deep grey, semi-translucent variety, bearing marks of the intense strains to which it has been subjected, and usually associated with the hornblende schists, or an opaque, milky white kind often found traversing chloritic schists, and perhaps connected with the intrusion of basic dykes which are common in the system and of later age. While both varieties may be auriferous, the former kind more often carries gold in the south, while the reverse is commoner further north. This, however, is not an invariable rule; white veins have been found among the hornblende schists of the south and may be gold-bearing. In the case of the Kolar goldfield, now to be briefly described, some geologists trace a connexion between the auriferous veins and the hornblende schists, while others regard them as the end-product, the hydro-thermal stage of the Champion Granite, formed by quartz-bearing solutions emanating from the cooling magma, filling the fractures in the schists and in some instances replacing their walls by quartz.

The Kolar goldfield is in the district of the same name in eastern Mysore, about 125 miles west of Madras, and lies on a plateau 2,800 feet above sea level. Warren, in 1802, first directed attention to it after seeing shallow mining in eluvial deposits from which fragmentary quartz was extracted, crushed, and the gold recovered by washing and amalgamation. In earlier times, as later exploration proved, shafts had been sunk into the solid quartz, reaching a depth of 300 feet. Modern history dates from 1871, when Lavelle obtained the first concession and commenced a shaft on what is now the Ooregum Company's block. Between 1878 and 1882 various companies were formed to undertake gold mining, but by the end of 1884 most of them had exhausted their resources,

and it was only a final effort on the part of the Mysore Company which in that year disclosed rich ore in the pillars of an ancient mine. From that time the history of the field, under the capable technical direction of Messrs John Taylor & Sons, has been one of practically uninterrupted success. The narrow belt of Dharwar schists on which the goldfield lies can be followed for about 50 miles from north to south, but the productive portion is confined to a length of about $4\frac{1}{2}$ miles, on which are situated from north to south the Balaghat, Nundydroog, Ooregum, Champion Reef and Mysore mines, though the Nundydroog Company acquired the property of the Balaghat concern in 1932. From the commencement of operations until the end of March 1951 the total quantity of gold won amounted to 21,842,902 oz., valued at Rs 169·61 crores, while dividends paid to the end of March 1951 totalled Rs 37·82 crores. The royalties and taxes (including Gold Duty) paid by all the mines to the Government of Mysore to 31 March 1951 amounted to Rs 23·81 crores.

There are in all about thirty veins on the Kolar field, averaging 3 to 4 feet in width, though markedly lenticular, swelling and contracting at irregular intervals in both strike and dip. With few exceptions they are parallel to the foliation of the schists and are in fact the filled-in fissures which have opened along their lines of greatest weakness. They strike approximately north and south and in most cases dip westwards at 40° to 50° , steepening to almost vertical at great depths. Practically the whole of the gold, however, has come from one vein of this more or less parallel series and it is known as the Champion Reef. Its quartz is bluish-grey, clean and glassy, made up of large, irregularly locked grains with innumerable minute vesicles distributed throughout it, and its gold content is generally invisible to the naked eye. In places the vein bulges into large quartz bodies and in others splits into smaller veinlets. Characteristic of it are sharp folds, pitching at about 45° to the north, with thickened masses of quartz developed at the top and bottom of the folds and forming valuable sources of ore. The gold values are distributed in well-defined shoots, increase in 'finess' with depth and, according to Prior, are of later date than the quartz itself and than the large north-north-west, south-south-east faults which cross the field. Tourmaline is a very common accessory mineral; chloritoid is frequently seen; galena, arsenopyrite, pyrrhotite, pyrite, chalcopyrite, ilmenite, magnetite and scheelite have all been found with the gold. In the Oriental Lode there is no galena, its place being taken by small amounts of zinc blende and tellurides. Frequently associated with the quartz veins are thin, half-inch bands of pale green pyroxene in irregularly shaped crystals, often intergrown with calcite and partly altered to actinolite. In cases where the veins split into thin veinlets, these pyroxene bands increase until they form the chief constituent of the vein. The average grade of ore treated in the Kolar field

during the 15 months ending 31 March 1951 contained 6.62 dwt of gold per ton.

The deepest point reached in the Champion Reef mine was 9,233 feet in December 1951. Development is carried out by means of levels at vertical distances of 100 to 150 feet, and the total footage of the underground workings to date exceeds 600 miles. The gold content of the quartz is remarkably persistent with depth, and although individual ore shoots may come to an end, new ones are found to take their places. At the 33rd level it was found that the Mysore North fault had entered the Champion Reef property from the adjoining Mysore mine, with the result that the ore shoot of the Main Reef on its southern edge was cut out between the 33rd and 58th levels. The orebody gradually diminished along its strike and was ultimately lost in a major pegmatite zone. But below this again, two more ore shoots were found on either side of the fault. The northern one, termed the Central Ore Shoot, commenced from the 61st level, whereas the southern one, termed the Glen Ore Shoot, was discovered on the 68th horizon; its northern edge follows roughly the southern fringe of the fault, and its southern portion has isolated shoots of ore which are displaying a tendency to merge with the main orebody. The Glen Ore Shoot is indeed a unique occurrence of great magnitude covering an area of over 56 acres. Fluctuations of gold distribution in the lode channel are marked but the average for the main orebody is approximately 14.9 dwt over a stoping width of 66 inches. Up to June 1950, it had been successfully developed for a depth of 2,500 feet, with increasing lengths of economic values along its strike, the maximum being 1,300 feet at the 76th horizon.

The Ooregum mine, with a vertical depth of 9,876 feet in June 1953, was at that time the deepest mine in the world. Its main orebody laid near the southern boundary of the property and continued beyond it into the adjoining Champion Reef mine. The sequence of deep mining operations necessary to extract it so restricted output that the Ooregum Mining Co. Ltd had to cease working about the middle of 1953, when its rights were transferred to the Champion Reef Gold Mines of India (KGF) Ltd, who are at present mining in the area. At these great depths rock bursts have become a serious hazard, compelling the use of packed crib sets and heavy masonry walls in the stopes to resist the ground pressures. Rock temperatures of the order of 140°F. at 9,000 feet have necessitated the introduction of air-conditioning plant at all the mines of the field. In the Nundydroog mine a strong pyritic vein was intersected in 1949 about 2,000 feet to the west of the Main Reef on the 48th level. It had been mined in the past from the surface to a depth of 700 or 800 feet, where the workings had been abandoned. It is up to 25 feet in width with a steep varying westerly dip and an average grade of 5 to 6 dwt

of gold per ton. It has since been developed down to the 62nd level, or more than 5,000 feet vertically below the surface.

Kolar gold-bearing quartz is not refractory and yields its valuable contents to a simple combination of blanket concentration, amalgamation and cyaniding. Recovery averages over 98 per cent and the bars produced contain approximately 925 parts of fine gold and 70 parts per 1,000 of silver. Refining is carried out in the Bombay mint and the products—gold with 995 parts per 1,000 and fine silver—are sold in India.

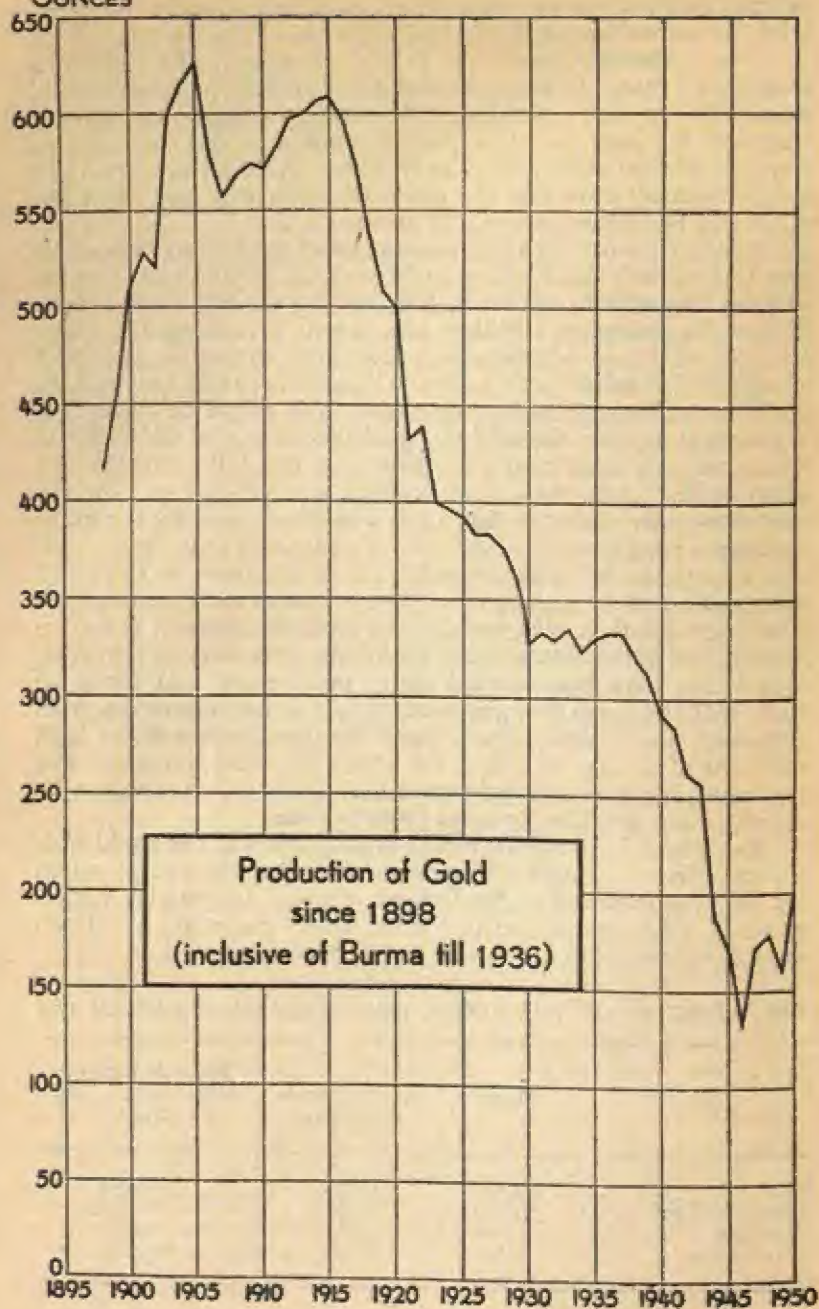
As and from 6 May 1949, the control of the mining companies was transferred from London to Mysore, under the management of John Taylor & Sons (India) Ltd, and for the first time in their history, the companies held their annual general meetings in Mysore in 1949. The peak of production, 616,758 oz. of gold, was attained in 1905; it fell below half a million ounces in 1919 and has declined more or less continuously since then. The graph on page 128, although it includes the all-India gold production, of which Kolar forms the only significant part, illustrates this fall. For the five years ending 1938, the annual average was 326,188 oz.; for the next five-yearly period ending 1943, 280,408 oz. and for the quinquennium 1944 to 1948, 167,921 oz. In 1949 and 1950 the average was 175,258 oz., being 97 per cent of the total production of Indian gold, valued at Rs 5,45,43,140. These records need no explanation: they tell their own story of the gradual approach of an inevitable end of the abstraction of gold from those veins on the Kolar field which have been worked for so many years. At the same time, that end is not yet; given a sympathetic administration, freedom from acute labour troubles and the maintenance of the high standard of mining technique for which the field has long been renowned, it can be safely assumed that Kolar will continue to be an important producer for some years to come.

Kolar itself is one of the model mining towns of the world with a population of 134,000. The mines as a whole find employment for 189 Europeans and 23,700 Indians, of whom 14,870 work underground. The ore reserves of the individual mines on 31 March 1951 are given below:

ORE RESERVES OF THE KOLAR GOLDFIELD ON 31 MARCH 1951

Mine	Tons	Average Grade dwt per ton	Probable Reserves of Low-grade Ore Tons
Mysore	261,200	12·35	208,900
Champion Reef	527,409	11·47	66,384
Ooregum	155,026	9·15	57,870
Nundydroog	322,570	10·06	272,086

THOUSAND
OUNCES



Hundreds of old gold workings have been found scattered over the surface of the Dharwar rocks in Mysore, but it is said that in the majority of instances they do not indicate the existence of valuable deposits beneath them. Equally disappointing has been the investigation of the numerous quartz veins which traverse the schists and crop out at the surface. Smeeth and Iyengar summed the matter up in the following statement: 'We may take it as an almost universal rule that outcropping veins are valueless.' After pointing out that it is possible that some zones of low-grade ore may be found of sufficient extent and under conditions favourable enough for cheap treatment to permit of their being worked, these writers conclude by saying: 'We cannot shut our eyes to the fact that the hopes based on the success of the Kolar mines and on the existence of numerous old workings have dwindled very seriously with the progress of survey work and deep prospecting.' It would be premature to assume, however, that this statement represents the last word on the subject. It now seems certain that the Kolar veins are closely associated in genetic relationship with the final phases of the Champion granite or gneissic intrusions, but to what extent this mother rock, its pegmatites and quartz veins, exist outside Mysore, the Bellary district (formerly of Madras) and the Dharwar district of Bombay is quite unknown. In both these districts there are quartz veins probably identical in age and character with those of Kolar, and a little gold has already been found in the northern part of the Chitaldrug belt. In the Gadag area of the Dharwar district, blue, diaphanous quartz veins, similar to those of the Kolar field occur, but, on the authority of Sir Edwin Pascoe, a former Director of the Geological Survey of India, it is quite unknown to what extent they are gold-bearing as they have been very little prospected.

Numerous old gold mines are scattered about in various parts of the Raichur Doab and the Surapur taluk of the Gulbarga district of Hyderabad. On an irregular area of Dharwar rocks which stretches through Maski, from the vicinity of the Tungabhadra river to the Krishna, they reach the unusual depth of 640 feet below the surface, bearing witness to the skill of an ancient race of miners about whom both history and tradition are silent. Near the old workings groups of mortars of large and small sizes are to be found in which the gold-bearing ore was crushed. 'They are to be seen in abundance at Topuldodi,' writes Captain L. Munn, at one time Mining Engineer to the Government of Hyderabad, and he continues: 'At Wondalli there are large saucer-like hollows, made in the trappoid rock, in which the ore was pounded by means of granite crushers of great size. These crushers must have been brought from a great distance, and from their enormous sizes it is evident that they were not worked by hand, but by means of some sort of framework which afforded leverage.'

The modern search for gold in Hyderabad dates back to 1886, when the Hyderabad (Deccan) Co. conducted prospecting operations

over a period of twelve years, 1887 to 1899. More than three hundred old workings were discovered in parts of Hutti, Wondalli, Maski, Topuldodi, and Budhini in the Raichur Doab, as well as in the Manglur field in the Surapur taluk of Gulbarga. Most of these are stated to have received some attention, but it is important to note that only a few of them were bottomed. Realizing that diffused operations of this sort were a heavy drain on its resources, the Hyderabad (Deccan) Co. formed subsidiary concerns to undertake development work. These were:—(1) The Wondalli (Deccan) Gold Mining Co. Ltd which began work at Wondalli about 1895, but ceased in 1900. Its most productive year was 1899, when 18,970 tons of quartz were crushed for a return of 7,822 oz. of gold. The yield of gold from Hyderabad from 1898 to 1900, amounting to £54,310, was almost exclusively the produce of this mine. (2) The Hutti (Nizam's) Gold Mines Ltd started crushing with 10 heads of stamps (later increased to 30 heads) in 1903 and ceased in 1920, after the mine had reached a depth of 3,500 feet and gold worth £1,010,757 had been extracted. (3) The Topuldodi Gold Mines Ltd commenced mining in the vicinity of Topuldodi and Chinchkerki in 1905 and ceased operations in 1908. Its only recorded production was worth £8,319 in 1908.

Another company, the Deccan Gold Fields Development Co. Ltd, was formed in 1905 with the object of examining all the old workings left untouched by earlier prospecting operations. It is said to have paid particular attention to the Manglur field, but its activities came to an end with the outbreak of the first world war in 1914. With the exception of revision surveys by the Hyderabad Geological Department which resulted in the discovery of a new area near Hunkuni, in the Deodrug taluk, where a long line of old workings was partially opened up, nothing further was done until the Hyderabad Government financed a programme of detailed prospecting in the Manglur, Hutti and Maski areas, conducted by John Taylor & Sons, who commenced their explorations in 1937. In the Hutti area it was found that more or less continuous ancient workings exist on various veins over a total length of 11,000 feet of which only 3,100 feet had been explored underground by the former Hutti Company. In addition to the Main Mine, the old Village Reef and Oakley's mines were unwatered, developed and resampled so that by 1942, when work was temporarily suspended owing to the war, ore reserves totalling 229,536 tons, averaging 4.62 dwt of gold per ton, had been proved. The Hyderabad Gold Mines Co. Ltd was formed in 1948 with an authorized capital of Rs 1 crore and a pilot plant commenced crushing in September of that year. It was replaced by the main mill in November 1949, to which a cyanidation plant was added in August 1950 for the recovery of gold from the tailings. The present mill has a capacity of 150 tons a day but it is proposed to double this in the near future in order to increase production and

reduce working costs. From 1948 to 1951 inclusive 20,336 fine oz. of gold, valued at Rs 70,98,290 had been recovered. The ore reserves at the end of September 1951 were estimated to be 128,502 tons of an average value of 5.32 dwt and excluding some 80,000 tons of prospective ore of an average grade of 5.34 dwt of gold per ton. It is noteworthy that besides the single vein previously known in the Village Mine, at least two new ones containing gold in profitable quantities have been found.

Some geologists believe that an extension of the Kolar field may possibly be found in that part of the Chittoor district of Andhra which lies to the south-east of Kolar; in any case it has been proved that the autoclastic conglomerates of the Kolar field occur again near Bisanattam where, in addition, a tongue of Champion granite-gneiss projects into hornblende schists of Dharwar age. Between 1894 and 1902 quartz veins in this vicinity were opened up to a depth of over 750 feet by the Mysore Reefs Kangundi Gold Mining Co. Ltd, and approximately 10,000 tons of ore were crushed and amalgamated with a recovery, it is said, of about 6,000 oz. of gold. Several further ventures have been made here during the past 30 years, the latest being by the South Kolar Gold Mines Ltd of Bombay, who between 1945 and 1948 partially reconditioned the old shaft, dewatered the mine to the 320-foot level and sampled the exposed vein. This is said to be in hornblende schist, to average 22 inches in width, to strike north-north-west and south-south-east, to dip westerly and to carry an average value of 5.19 dwt of gold. Some mining was done between July 1949 and June 1950, when operations ceased through lack of capital after recovery of a small amount of gold. Small amounts of scheelite (calcium tungstate, CaWO_4) and of cassiterite, the oxide of tin, SnO_2 , have been detected in the old dumps at Kangundi. The auriferous quartz veins, according to S. Krishnaswamy, branch off and peter out into detached stringers and veins as traced southwards. The gold content is generally very low, seldom exceeding 2 dwt per ton.

Of the many old workings in Mysore, only the Bellara mine in Tumkur district was being developed by the Government of the State, under a ten-year scheme to remove all the gold-bearing quartz obtainable before the locality is submerged by the Lakka-valli reservoir, and till 1953-4, 5,447 *tolas* of crude sponge gold, valued at Rs 5,53,407, had been obtained before its closure.

In 1874, R. Bruce Foote found an auriferous quartz vein near Dambal, Dharwar district, Bombay, on the great belt of Dharwar rocks, known as the Dambal-Chiknayakanhalli band, which stretches from the southern part of Bombay State into southern Mysore. The area contains abundant ancient workings and was prospected between 1902 and 1904 by the Dharwar Reefs Gold Mining Co. Ltd, who started crushing in 1907, their ore coming from a mine near Kabligatti. In that year 4,916 oz. of gold were

obtained and in 1908 the output increased to 7,242 oz.; but it then began to decline, and the mine, together with others that were under development in the neighbourhood, was closed in 1911. The Kabligatti vein system has been followed southwards for 8 miles into Sangli, and a parallel series occurs near Hosur, about $3\frac{1}{2}$ miles to the west. These were also under development in 1906 both by the Dharwar Reefs Company and by other concerns, but none of them ever reached the producing stage. Auriferous quartz veins are very numerous in this region, but they are individually of no great extent or thickness; belonging to two separate series, an older of blue, diaphanous quartz, associated with the metamorphosed igneous rocks, and a younger of ferruginous, white quartz veins, associated at Kabligatti with carbonaceous phyllites, they finally dispel the older idea that the gold is confined exclusively to blue quartz veins of the Kolar type. The ancient workings, which in places reached a depth of 300 feet, are restricted to two veins of white quartz, though actually both varieties may be gold-bearing. It should be stressed that although the veins of Kolar and some of the other goldfields are genetic associates of the Champion granite-gneiss, gold has also been found in veins of later periods, some of them perhaps post-Archæan. The total recorded production of the Dharwar field was worth £80,209.

A belt of Dharwar schists stretching north and south through the Anantapur district of Andhra, known as the Penukonda belt, contains several large quartz veins associated with chloritic and hornblendic schists. The occurrence of old workings near Ramgiri led in 1905 to the formation of the Anantapur Gold Field Ltd, and in 1908 to that of the North Anantapur and Jibutli Gold Mines Companies, with mines of the same names. At the former a depth of 1,150 feet was reached by 1924, when operations ceased after yielding gold to the value of £782,023.

The Chota Nagpur division of Bihar is traversed from east to west by a series of argillites, phyllites, talc and mica schists of Dharwar age which enclose quartz veins of both types mentioned earlier, but here the gold is found, as a rule, in the opaque white and younger veins. Many altered basic intrusives related to epidiorites occur in the gold-bearing areas. Both veins and old workings are very numerous, and small quantities of alluvial gold occur in most of the streams, where its extraction on a small scale by the tribesfolk of Singhbhum is still carried on. Following the discovery of rich ground in the Sonapet valley in 1888, in 1890 a gold boom, centred on this region, occurred in Calcutta, and thirty-two companies, with a total capital of nearly £1,000,000, were formed, but by the end of 1892 only two of them remained in existence. Later investigations by J. M. Maclaren proved that the gravels are too low in gold to be worked profitably. Various localities are known in which auriferous veins occur, but in this case again, assay results have been uniformly poor, though favourable

territory for further prospecting is believed to exist. The distribution of the gold-bearing veins of Singhbhum suggests, according to J. A. Dunn, a relationship with the late basic intrusive phase of the Dalma volcanic rocks. The discovery of old workings near Kundrukocha, in Dhalbhum, close to the Mayurbhanj border, on a series of veins of blue-grey quartz in Dharwarian phyllites, led to the formation of the Dhalbhum Gold & Minerals Prospecting Co. Ltd, which recovered 6,034 oz., valued at £26,839, between the years 1915 and 1920. All but 250 oz. of this total came from one pocket at Porojarna. According to Sir Lewis Fermor, the richer veins average only about 4 dwt to the ton, though the Porojarna shoot averaged about 20 dwt. The Kundrukocha mines have been leased to E. O. Murray and one of them is again being worked intermittently.

Certain auriferous quartz veins which occur in quartzites, phyllites and quartz schists and are traceable for about three-quarters of a mile at Lawa in Manbhum, have been investigated recently by the Lawa Gold Mines Ltd. The gold content is said to average 7 dwt per ton and to be associated with copper ores and tellurides. Further occurrences of gold-bearing quartz veins are known at Ichagar, Burndih and Maysara, in the neighbourhood of Lawa. At the last-named locality, where rich ore pockets are sometimes found, according to D. K. Chandra, a Company entitled Maysara Development Ltd was engaged in prospecting work.

Dr J. A. Dunn believed that no gold deposits have as yet been found in southern Chota Nagpur which offer scope for the activities of mining companies with large capital, adding, however, that there are opportunities for individual prospectors and even for small syndicates. New veins may still be discovered, particularly in the schist zone underlying the lavas of the Iron Ore Series, and prospecting should be concentrated on the so-called blue quartz veins.

The gold occurrences of the Mingin Hills in Upper Burma, though of no commercial value, as far as is known at present, are of interest in that they furnish an example of the occurrence of the metal entirely different from that found in the Dharwarian rocks of the Indian peninsula. The hills which lie between the Mu and Meza streams, both tributaries of the Irrawaddy, are, according to F. Noetling, formed of eruptive volcanic rocks. Five localities are known on the eastern flanks where veins containing auriferous pyrites occur, and three others where the mineral has been mined by the Burmese from volcanic ash. One of the veins was mined near Kyaukpazat between 1898 and 1903, when the pay shoot was lost and the enterprise abandoned. This vein averaged $3\frac{1}{2}$ feet in width, 240 feet in length and was followed down to a depth of 420 feet. It was occasionally clean but more often well mineralized, carrying 5 per cent of chalcopyrite, pyrite, galena, franklinite and small amounts of altaite, the telluride of lead. The country rocks were tuffs and breccias of andesitic facies and Tertiary age, intruded

in places by quartz diorites. The total production from the Kyaukpazat mine was probably worth between £19,000 and £20,000.

Alluvial gold is found in the sands of many rivers in India, Pakistan and Burma, in fact, as La Touche points out, there is hardly a province of the former Indian Empire in which its recovery from river sands is not, or has not been, practised by the inhabitants, though the quantity which appears in the official returns from such sources is insignificant and the statistics are known to be incomplete. In the case of rivers draining the Indo-Gangetic plain, including the valley of the Brahmaputra in Assam, the metal is derived not only from rocks which were its original home, but for the most part from others into which it was introduced along with the transported material of which they are composed. The regular recovery of a few ounces used to be reported annually from the Singhbhum district of Bihar; from the Katha and Upper Chindwin districts of Burma; from Kashmir, where washing is carried on along the Indus valley in Gilgit and Baltistan; from the Punjab, where it is practised in the Attock, Ambala and Jhelum districts, and from the Garhwal and Bijnor districts of Uttar Pradesh. The alluvial miner in these and other regions is, as often as not, a cultivator who adds to his meagre income by indulging in the speculative pastime of gold-washing when the crops do not demand his immediate attention. The small quantities of the precious metal so obtained in most cases probably find their way direct to the local goldsmith to be turned into jewellery, and in so doing short-circuit the path to the revenue collector's office.

Dr J. M. Maclaren, who made a searching investigation of the whole matter, concluded that in few countries is alluvial gold more widely distributed than it is in India, which in this case includes both Pakistan and Burma, and in few countries does it show less tendency to aggregation under the influence of running water. He pointed out that wherever streams drain areas of ancient schistose rocks and possess the proper gradients for the deposition of gravel, they carry small amounts of gold. Such conditions apply in many parts of Mysore, Madras, Bombay, Hyderabad, Madhya Bharat and Chota Nagpur, and to these we may add Upper Burma, Tenasserim and the Shan States, Chitral, parts of the upper Indus valley and certain tributaries of the Brahmaputra in Upper Assam; 'but in no case,' wrote Maclaren, 'so far as is yet known, are the gravels sufficiently rich to warrant European examination, though they may in many cases afford a few weeks' employment during the cold weather to the local washer, who is content to work for a return of $1\frac{1}{2}$ to 2 pence per day'. Maclaren's own investigations in the richest streams of Chota Nagpur proved that the alluvial ground contained on the average about 1 to $1\frac{1}{2}$ grains of gold per cubic yard, and that the six inches or so of the bottom gravel, which under normal circumstances would naturally be the richest, yielded

not more than 2 grains per cubic yard. Maclaren's work was done in 1903 and in the intervening years nothing has been discovered to lead to any modification of his opinions. Discussing them in 1942, after his own extensive surveys in Singhbhum, Dr J. A. Dunn wrote: 'Washing for alluvial gold is likely to continue as an intermittent occupation of the villagers in certain localities. There is little probability that alluvial deposits will be found such as would pay a company to sluice on modern methods. The values quoted by Maclaren of 1 to 2 grains of gold per cubic yard in the Sonapet valley would be payable under certain conditions of topography, rainfall and depth of alluvium. But in the Sonapet valley the thin alluvium with rocky outcrops is not conducive to sluicing on a large scale with low costs, and any attempt to do so must be condemned at once.' It must be recognized that the seasonal changes from the low waters of the dry weather to the raging floods of the rains, which characterize rivers subject to the periodic variations of a monsoon climate, do not bring about the tranquil conditions necessary for the accumulation of thick gold-bearing gravel deposits.

Gold-washing thrived at one time in those parts of Jashpur, Madhya Pradesh, which lie south of Latitude $22^{\circ}39'$, within the drainage areas of the Ib river and its tributaries the Maini and Sonajori; old workings in the gravels are very numerous and small-scale work still persists. Recent investigations have shown that the values are found mainly in those gravels which lie on a gneissic bed rock and under alluvium which may range up to 30 feet in thickness. This gravel itself is up to 10 feet in thickness and carries an average gold content of 2 grains per cubic yard, but the available reserves total little more than one quarter of a million cubic yards and are scattered in patches up and down the banks of several streams. The gold has been traced to quartz veins traversing the gneissose granite country rock and random samples yielded up to 16 dwt per ton.

Similar deposits are still being worked in the Koraput district of Orissa, particularly in the Kolab river below its junction with the Rongpani; in the Rongpani itself as well as in its tributaries the Jan and Dharan *gedda*, and in the Garia *nadi* where it debouches from the hills near Doraguda. The yields are said to average 1 to 3 grains per cubic yard. Other similar operations continue in the alluvium of the Brahmani river in Bonai and Bamra and in the bed of the Sona *nadi* in Kharsawan. The alluvium of certain streams in Khairagarh and Kanker, Madhya Pradesh, is known to be auriferous, while a few ounces are still recovered every year from the Sona *nadi*, near Kalagarh, in Garhwal, Uttar Pradesh.

The sparsely distributed alluvial gold of several of the Himalayan rivers and their tributaries, not only in Garhwal, but also in Kumaun, the Kangra valley, the Simla Hills, the Punjab and the North-West Frontier Province of Pakistan, is still won on a small scale, as, for instance, on the Indus around and above Attock,

on the Soan in the Potwar, and on the Teria Panjkora and Swat tributaries in the north-western part of the North-West Frontier Province. The Bunhar and Kahan, tributaries of the Jhelum river, also contain alluvial gold. Certain of the acid volcanic rocks north of Injan Dheri in the Mardan district contain small quantities of gold; tuffaceous rhyolites collected by A. L. Coulson in this vicinity yielded 0.3 to 4.3 dwt per ton. These rocks may be the source of the alluvial gold of the Kabul river and its tributary the Kalpani *nala* which have been the scene of washing operations in past years. Gold-washing has been carried on in Chitral from time immemorial as a State monopoly, the workers performing their task in return for the small estates they enjoy and never exerting themselves to any great extent. During the summer the Chitral river is in flood and in the winter the water is too cold to allow work to be done; the working season therefore only extends from mid-September to the end of November in the autumn, and from mid-March to the end of May in the spring. The only tributaries of the Chitral river which carry gold are the Reshun, Kuragh and Roman *gols*, and although washing operations are prosecuted for some considerable distance upstream towards Mastuj, they are concentrated mainly downstream, between Drosh and the Afghan border. Usually, attention is confined to the recent deposits, but in some places, according to Habib Rahman of the Geological Survey of Pakistan, as in the neighbourhood of Dammar Nisar, older gravels lying 15 to 20 feet above the present level of the river are worked.

The pioneers of gold dredging in Burma were W. R. Moore and J. Terndrup, through whose enterprise a company known as the Burma Gold Dredging Co. Ltd was formed which carried on operations in the upper reaches of the Irrawaddy and about the confluence of the N^omai Hka and the Mali Hka, in the Myitkyina district, between 1903 and 1918. The average value of the gravels was about 3 grains per cubic yard, and a total of 56,624 oz. of gold, worth £217,381, was recovered, together with small quantities of platinum and its sister metals. The dredges were eventually removed to the Tavoy district and helped in the successful inauguration of the tin dredging industry there. The Mandalay Gold Dredging Co. Ltd obtained a large concession in the Lower Chindwin river between Minsin and Homalin, but the dredger sent there in 1905 was wrecked on the way and the undertaking abandoned. In 1905, a dredger erected on the Namma river, a tributary of the Salween in the Northern Shan States, where preliminary exploration is alleged to have proved the existence of approximately 40 million cubic yards of gravel, with an average value of 5.43 grains of gold per cubic yard, was found unable to perform its task owing to the cementation of the ground by calcium carbonate.

Many localities where indigenous gold-washing is, or has been, carried on, in the Chindwin, Katha and Myitkyina districts are

listed in the writings of H. S. Bion, H. L. Chhibber and E. L. G. Clegg, and to these V. P. Sondhi has added others mainly in the Southern Shan States. The richest occurrences are perhaps those of the Uyu valley, a tributary of the Chindwin, which it enters near Homalin, but they are said to be so intermixed with barren sands and gravels that systematic large-scale operations would not be profitable. New occurrences described by V. P. Sondhi include an almost constant band of gold-bearing gravel, three feet in thickness, at the base of river deposits in parts of the Panglang valley, worked in the past by Chinese miners from pits sunk through its alluvial covering; the presence of gold in streams draining areas occupied by Chaung Magyi rocks between the Salween valley and Kengtung, and the auriferous gravel and boulder terraces in many of the valleys between Kengtung and the Thai border. In the Mong Hpayak, Monglen and Hawngluk valleys, the gravels are generally buried under 5 to 10 feet of barren overburden. The gravels of a number of streams draining the northern side of the Mogok massif, as well as those of other tributaries of the Shweli river in Mongmit, are also known to carry gold. While much still remains to be done, such systematic prospecting of the gold-bearing alluvial deposits of Burma as has been undertaken in the past has proved that, in most cases, they are too lean to hold out hopes of successful dredging. It is possible, however, that better ground remains to be discovered, especially in the upper branches of the Irrawaddy and Chindwin and their tributaries.

No attempt is made here to discuss the intricate ebb and flow of the import and export trades in gold bullion and coins into and out of India in pre-independence days: it must suffice to repeat the official opinion that at the present time India is just self-sufficient as regards her own requirements of gold, which are mostly for ornaments, and that, as a consequence, some measure of control was essential for conservation purposes. Before the last war gold was exported in huge quantities, the annual average amount for the five years ending 1938 being 3,725,383 oz., valued at Rs 34,34,94,121, against imports of 115,110 oz., valued at Rs 1,14,52,579. This led to the introduction of controls to regulate the outward flow of the precious metal. For the three years ending 1946, exports averaged 25,291 oz., worth Rs 42,95,358, and by 1948 no gold was leaving the country. Imports for the same three years averaged 66,098 oz., valued at Rs 1,30,71,678.

SILVER

More than half of the world's silver, which in the period 1934-8 averaged some 241½ million ounces yearly, is said to be won not from silver mines, but as a by-product from argentiferous lead, zinc and copper ores, and although many of the lead ores which have been found in small quantities at numerous localities in India,

Pakistan and Burma have proved to be silver-bearing, not one of them has yet proved of any economic importance, with the single exception of those of Bawdwin in the Shan States (see LEAD).

The silver minerals in the Bawdwin ore are not visible to the naked eye, but by microscopic study J. A. Dunn demonstrated the presence of pyrrargyrite at all depths in the mine, either alone or replacing tetrahedrite, boulangerite and bournonite. Pyrrargyrite, or Ruby Silver Ore, is a sulphantimonite of silver, $3\text{Ag}_2\text{S}\cdot\text{Sb}_2\text{S}_3$, and contains 59.8 per cent of the metal; tetrahedrite, a sulphantimonite of copper, $4\text{Cu}_2\text{S}\cdot\text{Sb}_2\text{S}_3$; boulangerite, a sulphantimonite of lead, $5\text{PbS}\cdot 2\text{Sb}_2\text{S}_3$; and bournonite, a sulphantimonite of both lead and copper, $2\text{PbS}\cdot\text{Cu}_2\text{S}\cdot\text{Sb}_2\text{S}_3$. Some of the silver is also present in solid solution in the galena of the Bawdwin ores. As a rough indication of the amount of silver present in the ore, it may be taken that the general mixture of galena and zinc blende as mined contains approximately 1 oz. of silver for every unit per cent of lead. Taken over a number of years an average of 1 oz. of silver was obtained for every 1.1 per cent of lead.

It is instructive to trace the passage of the silver in its progress from the mine to the refinery, for the treatment of the run-of-mine ore in the milling and flotation processes resulted in an increased percentage of silver in some of the products and a smaller quantity in others. For instance, in one pre-war year, the ore delivered to the mill from the mine contained:

Silver 20.5 oz.; Lead 24.93 per cent; Zinc 12.76 per cent. In the next table the composition of some of the products made in the mill at Nam Tu from this ore is shown: all of them, with the exception of the zinc concentrates exported to Europe for treatment, were smelted on the spot.

COMPOSITIONS OF MILLED PRODUCTS OF ORE FROM BAWDWIN

PRODUCT	ASSAY VALUE			
	Silver	Lead	Zinc	Copper
	oz.	%	%	%
Coarse Concentrate	45.86	65.03	9.10	0.33
Float Concentrate	40.24	70.18	7.32	0.50
Copper Concentrate	135.70	34.77	13.06	9.85
Iron Concentrate	11.52	14.41	12.15	0.57
Zinc Concentrate	9.02	6.01	51.66	..

The assay figures demonstrate how the silver is associated with the lead and copper rather than with the zinc, as indeed is only to be expected from the mineralogical constitution of the ores. A series of average assay values of some varieties of hard lead and

of the copper matte produced by smelting these concentrates is given below.

COMPOSITIONS OF SOME SMELTER PRODUCTS MADE FROM
BAWDWIN ORE

SOURCE	Silver	Lead	Copper
	oz.	%	%
Hard Lead from Ore	68.13	96.92	....
Hard Lead from Copper Concentrates	301.67	94.88	....
Hard Lead from Iron Concentrates..	72.05	94.84	....
High-Grade Copper Matte	82.29	27.72	43.67

The silver was finally recovered from the hard lead in the refinery where the Parkes' process was in use. Statistics of silver production at Nam Tu from 1909 to 1940 are summarized in the table below. As the ore reserves at Bawdwin at the time of the Japanese invasion in 1942 totalled over three million tons with a silver content of over 15 oz. per ton, it is evident that large quantities will be forthcoming when mining operations resume their former activities. The processing of surface ore stocks during the year ended 30 June 1952 yielded a total of 231,670 ounces of refined silver. The reopening of the mine is described under LEAD, page 162.

PRODUCTION OF REFINED SILVER AT NAM TU, 1909-40

PERIOD	QUANTITY	VALUE
	oz.	£
1909-13	399,715	46,460
1914-18	4,831,504	679,222
1919-23	17,639,125	3,189,110
1924-8	28,632,070	3,766,634
1929-33	32,288,126	2,718,282
1934-8	29,669,932	2,906,625
1939-40	11,920,000	1,143,783
TOTAL ..	125,380,472	14,450,116

This total of more than 125 million ounces does not represent all the silver yielded by the mine, for varying small amounts remained in the zinc concentrates which were doubtless recovered in the countries to which they were sold; moreover, the copper matte which was exported for refining also contained a great deal. In the 162,241 tons of matte, valued at £3,790,113, produced from 1924 until the end of 1940, it is calculated that there were approximately 12½ million ounces of silver, for its average content only

once fell below 60 oz. per ton, attained a maximum of over 93 oz., and usually ranged between 70 and 80 oz. per ton. It should not be forgotten that the Chinese mined this ore deposit for its silver content alone for centuries, and the vast quantities of cupellation slags which they left behind were some measure of the large amounts of the metal which they recovered. Though primarily a lead-zinc-copper sulphide orebody, it is easy to understand how it obtained its Burmese name of *baw dwi*n, or 'silver mine'. The maximum silver production, as far as European mining is concerned, was attained in 1928, with 7,404,728 oz., which were worth £890,004. In later years somewhat smaller amounts were extracted, as a natural result of the deliberate reduction of the throughput of lead ore. India was the natural market for the Burmese silver, but in 1932, for the first time in its history, the Burma Corporation failed to dispose of its silver in India, whereupon the monthly production was shipped to England for sale in the open markets of the world. Production of refined silver from accumulated ore stocks commenced once more at Nam Tu in 1948, and from that time until the end of 1951, 381,093 oz. had been recovered.

The gold from the Kolar field of Mysore nearly always contains some silver which is recovered in the course of refining operations, and small quantities of similar origin were obtained from the Anantapur goldfield during its active life. The available statistics of the silver derived from these sources are summarized in the following table:

SILVER RECOVERED FROM INDIAN GOLD REFINING, 1915-50

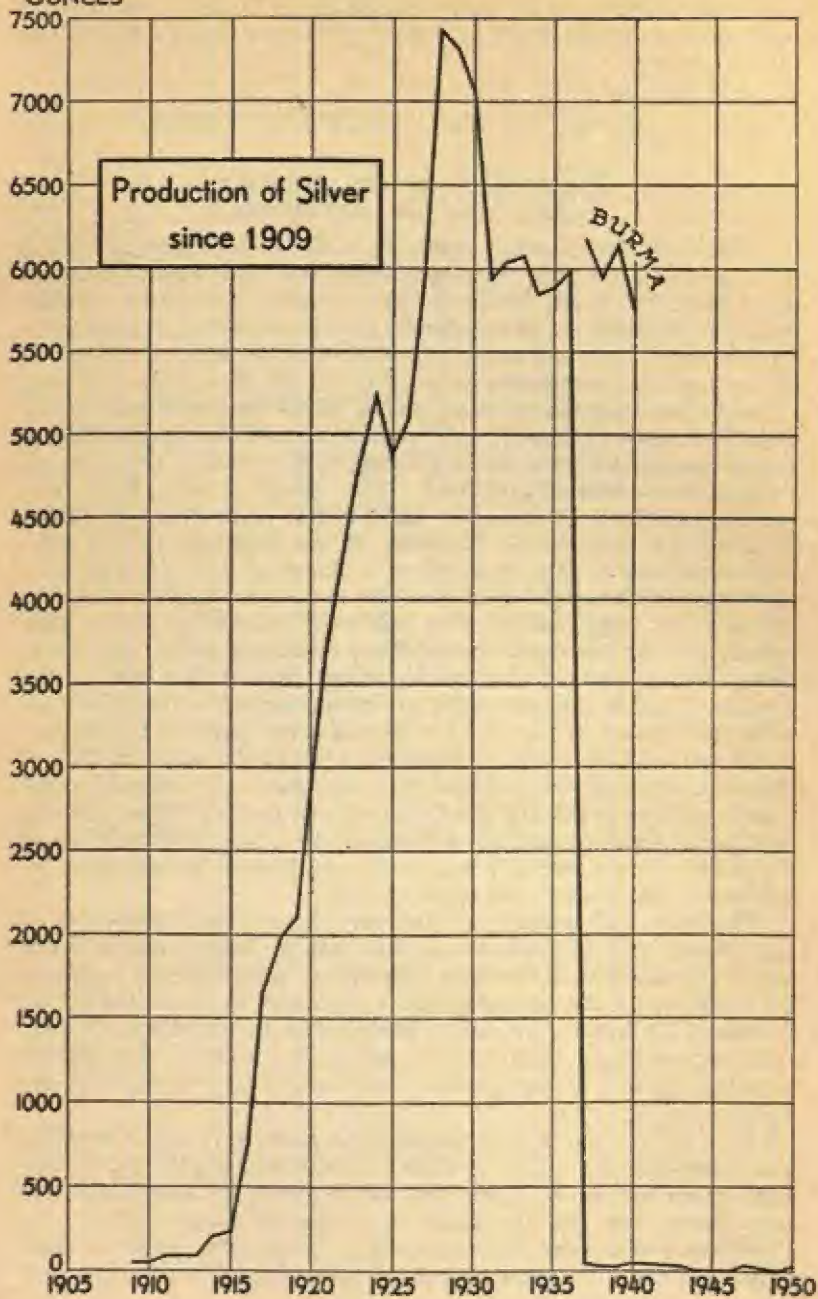
PERIOD	ANANTAPUR GOLDFIELD		KOLAR GOLDFIELD	
	oz.	£	oz.	£
1915-18	4,324	607	....	....
1919-23	2,895	531	124,940*	22,589
1924-8	478**	47	109,781	14,060
1929-33 .. ..	....	....	112,212	11,576
1934-8 .. ..	....	....	122,250	13,221
1939-43 .. ..	....	....	107,683	16,514
1944-8 .. ..	....	....	63,434	18,917
1949-50 .. ..	....	....	26,951	9,048

* For four years only. Returns commenced in 1920.

** For four years only. No production in 1928.

The lead and zinc concentrates from Zawar in Udaipur, Rajasthan, contain respectively more than 24 and 5 oz. of silver per ton. The recovery of the silver commenced at the lead smelter of the Metal Corporation of India at Tundoo in the Jharia coalfield in February 1954, and up to June 1954, 63,348 fine ounces of silver had been produced.

THOUSAND
OUNCES



India imports large quantities of silver bullion, the average quantity for the two years 1949 and 1950 being 103,531 oz., valued at Rs 4,29,597.

METALS OF THE PLATINUM GROUP

PLATINUM, PALLADIUM, RHODIUM, IRIDIUM, OSMIUM, RUTHENIUM

Platinum, which occurs naturally in the metallic form, is almost always associated with varying quantities of the related elements palladium, rhodium, iridium, osmium and ruthenium. Iridosmine, or osmiridium, is a natural alloy of iridium and osmium in variable amounts, and small percentages of the other members of the group are also usually present in it. In 1831, James Prinsep proved that a button of white metal, which had been sent to the Asiatic Society of Bengal, was an alloy containing 25 per cent of platinum and 40 per cent of iridosmine, the remainder consisting of gold, iron, arsenic and lead. The specimen came from Ava, in Burma, then, as now, an independent country, and Major Burney, the first British Resident at the Burmese Court, later explained how it was obtained with the gold dust from streams entering the Chindwin river from the west, near Kanni. Captain Hannay, in 1857, stated that platinum occurs in appreciable quantity in the auriferous sands of the Hukawng valley, and H. S. Bion, who examined the gold-bearing alluvial deposits of the Chindwin and its tributary the Uyu in 1912, reported that platinum with osmiridium was detected in almost every locality, but in very small amounts, its mode of occurrence being the same as that of the gold. In 1927, H. L. Chhibber investigated alluvial gold workings in another portion of the Uyu valley in the Myitkyina district, and found small quantities of platinum as a constant associate of the gold. It was carefully removed from the gold concentrates by the local washers and then thrown away.

Platinum and iridosmine then are characteristic associates of the alluvial gold of the rivers in the north of Burma, and it is not surprising therefore to find that 'platinum' was recovered regularly by the Burma Gold Dredging Co. Ltd during its treatment of the gravels of the Irrawaddy and its branches in the Myitkyina district, between 1903 and 1918. The records are probably incomplete, but they show a recovery of 219 oz., valued at £1,332, between 1911 and 1914.

It is more than a coincidence that platinum and iridosmine were identified by Mallet in 1882, accompanying gold in concentrates from the sands of the Noa Dihing river of Assam, for this river drains the opposite flanks of the Patkoi range, indeed, the distribution of the occurrences generally leads to the suspicion that they come from the great serpentine intrusions of the Patkois and

Arakan Yomas. The iridosmine from the Noa Dihing valley probably belongs to the osmium-rich variety known as siserskite. Sperrylite, platinum diarsenide, PtAs_2 , the only known native compound of the element, has been detected in heavy sand concentrates from some of the tributaries of the Irrawaddy in Myitkyina district, Burma.

The examination of a number of samples of Indian stream gold, stored in the Geological Survey Museum in Calcutta, proved the presence of platinum in specimens from streams in Singhbhum, Manbhum and in the Brahmini river in Orissa, and led Mallet to conclude: 'It seems not improbable that platinum is somewhat widely diffused in the southern part of Chota Nagpur, and perhaps throughout a larger area. But the specimens do not in themselves give ground for believing that it occurs in more than minute quantity. It is, however, possible that the gold washers may sometimes find grains sufficiently large to attract their attention, and that they reject them as useless.' Amongst the specimens containing platinum was one from the Gurma river near Dhadka, in Manbhum, and many years later E. O. Murray obtained silvery grains of platinum from much the same locality while panning for gold, the identification of the metal being confirmed later in the Geological Survey laboratory. J. A. Dunn thought that the origin of this platinum is possibly connected with the basic intrusives which crop out in the schists north of the Dalma lavas.

Traces of platinum have been reported in bauxite from Dhanggaon, Jabalpur district, Madhya Pradesh, and in bauxitic mud residues from Tungar Hill, Bassein, Bombay.

Apart from the uses of platinum and palladium in jewellery and for other decorative purposes, all the members of the group possess properties which make them of great value in many branches of industry. Such properties include their high melting-points, freedom from attack by most chemicals, high strength at elevated temperatures, resistance to electrical spark erosion, colour, reflectivity and catalytic activity. Platinum provides the chemist with both laboratory and works utensils; for large-scale operations platinum-clad or lined equipment is available. Alone, or alloyed with other members of the group, it is the catalytic agent for the conversion of sulphur-dioxide into the trioxide, in the manufacture of sulphuric acid; in the production of high-octane petrol and other petroleum products; in the production of nitric acid by the oxidation of ammonia, a process in which gauzes made of platinum-rhodium alloys are employed, and, with palladium, in many hydrogenation operations. The electro-chemical industry uses platinum anodes in the preparation of hydrogen peroxide and other highly oxidized substances, and anodes of platinum-iridium alloys in electro-plating and the recovery of metals from waste solutions. For the commercial manufacture of glass fibres platinum nozzles, being resistant to the attack of molten glass, are essential. In the

production of rayon, or artificial silk, the viscose solution is forced through tiny holes in a spinneret immediately before its coagulation into thread. These holes must be of extremely accurate dimensions and must retain their size and shape in constant use, entailing great resistance to both wear and corrosion; gold-platinum and platinum-rhodium alloys are therefore widely used. In the electrical trades, alloys of platinum with one or more of its sister elements, or with tungsten in some cases, have many applications, including contact points in magnetos, coils, sparking-plugs, telephone and other relays; in resistance thermometers, thermocouples for measuring high temperatures, furnace heating elements to operate at temperatures up to 1600°C . and so forth.

Palladium, like platinum, has both ornamental and useful applications and is now available in many prefabricated forms for personal adornment and decorative purposes, including foil beaten in the same manner as gold. Apart from the alloys already mentioned, there are others in which it plays an important part, particularly those employed in dental metallurgy for various fittings and clips. Owing to its remarkable power of adsorbing gases, palladium is an excellent catalyst for hydrogenation and dehydrogenation processes. In a spongy form it possesses the unusual property of adsorbing about 900 times its own volume of hydrogen and for this reason may be employed in the purification of this gas for special purposes.

Iridium is employed mainly as a hardener for alloys of the softer platinum-palladium group, particularly in the alloys used by the electrical industry, and in the manufacture of hypodermic needles, dental plates and surgical instruments, as well as in many forms of chemical apparatus. While the hardness of native platinum may vary between 4 and $4\frac{1}{2}$ on the Mohs' scale, that of the natural alloy of iridium and osmium ranges between 6 and 7.

Osmium is the heaviest of all the metals and, with a melting point of 2700°C ., the most refractory member of the platinum group, while its hardness is only exceeded by that of iridium. Iridosmine is widely employed in the tips of gold fountain-pen nibs on account of its qualities of hardness and resistance to ink corrosion. Similar alloys are used for bearings in watches and compasses and in the contact points of electrical devices.

Rhodium is a lustrous white metal which is said to be as malleable and ductile as silver. It is almost insoluble in all acids and has a higher melting point than either platinum or palladium— 1995°C ., compared with 1733°C . and 1555°C . respectively—and it possesses a more efficient reflecting surface than chromium; thus, apart from its utility in catalysts and alloys it is plated on to mirrors for searchlights and lamps, on to silverware to prevent tarnishing, and on to special electrical contacts and components to give them hard and resistant coverings. To the decorative alloys of platinum it imparts a brilliant surface after polishing.

Ruthenium, the rarest member of the group, occurs in iridosmine, but as a rule only to the extent of 4 or 5 per cent. It is described as white, hard and brittle, and next to osmium as the most infusible metal of the group. It is employed entirely as a hardening element in platinum and palladium-base alloys.

The metals of the platinum group are both rare and costly. Forty years ago the cost of platinum was a little less than that of gold, but by 1920, owing to its introduction into jewellery, it brought seven or eight times the price of gold. In later years, owing to increased production in Canada and elsewhere, the prices of platinum and its relatives decreased greatly. In the second edition of this book, published in 1936, the prevailing prices for August, 1935, are given as platinum £7 per oz., iridium between £9 and £10 per oz.; palladium, the cheapest metal of the group, about £4 and osmium between £7 and £9 per oz. By 1950 they had shared in the spectacular rises in the market value of most metals and, on the London market, platinum was then quoted at £27 per oz., or over twice the prevailing price of gold; palladium at £7 to £10 per oz.; rhodium at £40; iridium at £55; and osmium at £70 per oz., while ruthenium was obtainable at about the same cost as platinum.

The world's production of the platinum metals in 1948 is estimated to have been about 532,000 oz., to which Russia is thought to have contributed some 125,000 oz., while Canada gave 121,404 oz. of platinum and 108,343 oz. of the related metals, and South Africa 68,923 oz. of platinum and 5,520 oz. of osmiridium. By 1950 the South African output had increased to a total of 256,385 oz. and that of Canada to 269,442 oz.

The Canadian production is a by-product from the smelting of the Sudbury nickel-copper ores, in which the platinum metals and gold are present only to the extent of roughly two parts per million parts of ore, but, because of the large tonnage of ore dealt with, the actual output of these precious metals is very considerable. The sludges and residues which contain them are dealt with at the refinery of the Mond Nickel Co. Ltd at Acton, England. Most of the primary platinum deposits, including those of Canada, the Bushveldt in South Africa and the Urals region of Russia, are genetically associated with basic and ultrabasic rocks of the gabbro and peridotite families. Osmiridium is also a by-product of gold mining in the Transvaal. From the primary deposits, secondary ones of an alluvial, placer character are formed and have been worked on a large scale in the Urals, Colombia, Ethiopia, Alaska, Sierra Leone and elsewhere. All Indian ultrabasic rocks, especially the occurrences of dunite and similar types found in the neighbourhood of chromite deposits, and the eluvial and placer deposits derived from them, should be prospected for platinum, bearing in mind the fact that it was not a metal in which the miners of former times had any particular interest.

CHAPTER III

THE MORE IMPORTANT NON-FERROUS METALS

COPPER

THE copper ores of peninsular India, as V. Ball first pointed out, occur both in the older crystalline rocks and in several of the younger groups, as, for example, in those of Cuddapah, Bijawar and Aravalli age. In extra-peninsular India they are found for the most part in highly metamorphosed rocks, the precise age-relationships of which are not in all cases clear as yet. The commonest ore is the sulphide of copper and iron, copper pyrites or chalcopyrite, $\text{Cu}_2\text{S} \cdot \text{FeS}_2$, but near the outcrops it is usually altered into the green basic carbonate, malachite, $2\text{CuO} \cdot \text{CO}_2 \cdot \text{H}_2\text{O}$, or the blue basic carbonate, azurite, $3\text{CuO} \cdot 2\text{CO}_2 \cdot \text{H}_2\text{O}$. As a general rule, to which, however, there are some notable exceptions, Indian copper ores are not found in true lodes, but are either sparsely disseminated, or are locally concentrated in more or less extensive bunches or nests in the enclosing rocks; occasionally, cracks and small fissures have been filled with infiltrated ore and thus resemble true lodes.

Copper-bearing minerals have been reported from practically every State in India; from Baluchistan, the North-West Frontier region and the Punjab, in Pakistan; from the Shan States and the districts of Myitkyina, the Lower Chindwin, Salween, Amherst, Tavoy and Mergui in Burma: in both the peninsular and extra-peninsular regions of India, there are old copper mines of great antiquity whose histories are completely lost. Copper ores were smelted in prehistoric times and may have supplied the needs of the country for many later centuries, but in the days of the early European contacts with India, the mining and smelting of copper ores fell to quite a small scale, and fifty or sixty years ago was only carried on in the most petty manner. In the great majority of cases, the miners were unable to cope with the water which flooded their workings once they attained any noteworthy depth, and, in spite of the fact that labour costs must have been small, the metal which was turned out by the indigenous smelters could not be sold at competitive prices in the home markets against metal imported from abroad. Only the larger occurrences of copper ores can be dealt with here.

In the Singhbhum district of Bihar, a copper-bearing belt delineated by many ancient workings, and some 80 miles in length,

commences at Duarparam, on the Bamini river, in the Kera Estate, Singhbhum, and strikes in an easterly direction through Kharsawan and Seraikela into Dhalbhum, where it curves to the south-east through Rakha Mines and Mosaboni, ending to the south-east at Baharagora. The whole region took part in the great mountain-building, fold movements of Archaean times which resulted not only in well-defined geo-anticlines and synclines, but in the overturning towards the south of the close isoclinal folds which already filled in the broader structures. Then followed the culminating event, the development of a vast zone of overthrust along the southern limb of the central geo-anticline, which had formed the axis of this Archaean range. The rocks to the north, already completely metamorphosed, were thrust bodily against the less altered ones to the south, and along the whole length of the overthrust shearing was both close and complete. At the same time, extensive intrusions of soda-granite and granophyre were taking place, tongues of which, caught up in the thrust zone, were sheared as completely as the enclosing schists and in places entirely mylonitized. Two other shear zones indicate parallel lines of movement but do not concern us here. This tectonic history is important, for the movements which it records are the factors that have controlled the distribution of the later ore deposits of Singhbhum, and the copper belt for most of its length follows the main zone of overthrust across the country, while the lead ore deposits of Dhadka, in Manbhum, are probably related to a smaller overthrust further north.

The mineralization of the copper belt is genetically connected with the intrusion of the soda-granite, and its first stage was the formation of apatite-magnetite veins along the fissure planes. The deposition of the sulphide minerals which have formed the copper lodes followed as a second phase, both sets of minerals being regarded by J. A. Dunn as high-temperature liquations from the same residual soda-granite magma, relief of pressure rather than falling temperature being the controlling agency in the process. In most parts of the belt the copper-bearing minerals are too widely disseminated to reward exploitation in any notable degree, but this does not hold for the important section between Rajdah and Badia. At the Rakha Mines and at Mosaboni, both of which are within this particular section of the belt, the ore channels are best described as sheeted zones, containing one or more veins of solid sulphides together with mineralization of the sheared country rock of both walls. The solid ore may vary from a few inches to several feet in thickness, thinning out or tailing off when continued along the strike direction, to be followed by other occurrences more or less *en échelon*. The width of the mineralized side walls varies greatly; at the Rakha mines the lode channel contains values across an average width of 5 feet; at Mosaboni the average width is greater than this, and exceptionally has reached a width of 30 feet. At

Mosaboni the country rock is granite, altered to chlorite-biotite-quartz schist along the lode-channel; at the Rakha mines it is quartz schist changed into chlorite-sericite-quartz schist as it approaches the mineralized zone. The main sulphides are chalcopyrite and pyrrhotite, the magnetic sulphide of iron; the subordinate ore minerals are pyrite, pentlandite (the sulphide of iron and nickel, $2\text{FeS} \cdot \text{NiS}$), violarite (another sulphide of iron and nickel $(\text{NiFe})_2\text{S}_4$), and millerite, nickel sulphide (NiS). The gangue includes quartz, chlorite, biotite, tourmaline, magnetite and apatite. At the surface the sulphides have been oxidized, and in the dumps left by the ancient miners malachite, azurite, chrysocolla (a hydrated silicate of copper), cuprite (the red, cuprous oxide, Cu_2O), native copper, and, occasionally, chalcocite (cuprous sulphide, Cu_2S) are to be found. There are no zones of enrichment, and the products of supergene alteration give place gradually to normal primary sulphides, usually within much less than 200 feet in depth.

The first allusion to the copper ores of Singhbhum appears in a paper by W. Jones, dated 1829, but it was not until 1854, when J. C. Haughton described the old workings of Kharsawan, in the *Journal of the Asiatic Society of Bengal*, that their existence was definitely established. About this time, Emil Stoeckh was commissioned to examine the deposits on behalf of two Calcutta firms, and his report led to the formation of the first Singhbhum Copper Company in 1857. It commenced operations in Seraikela, at Namdup and Jamjora, and though it obtained good ore was so burdened by excessive royalties payable to the Rajas of Seraikela and Dhalbhum, by an expensive establishment of Saxon miners and English smelters, by the erection of costly smelting plant and by other premature and excessive expenditure, that it is not surprising that it was dissolved in 1859. A second concern, the Hindostan (Singhbhum) Copper Company, started mining at Rajdoha in 1862, but by 1864 had shared the fate of the earlier one. Valentine Ball's classical memoir on the Singhbhum region appeared in 1881, but it was not until 1891, with the formation of the Rajdoha Mining Company, that any further underground exploration was attempted. This company opened up a lode at Rakha but further work seems to have been prevented owing to lack of funds. About 1903, Sir Thomas Holland visited the copper belt and, impressed by its potentialities, as well as by the unsatisfactory state of definite knowledge concerning them, arranged for more detailed investigation. During the years 1906-8, selected localities were systematically drilled by the Geological Survey of India, in a successful campaign which directed renewed attention to the belt and laid the foundations of its modern industrial development. The Cape Copper Company bought the Rakha mines of the Rajdoha Mining Company in 1908, developed them actively, proved large ore reserves, erected a milling plant and commenced production in 1914. Smelting commenced in 1918 and continued until March

1923, when work ceased owing to financial difficulties, after the production of 180,095 tons of ore, valued at £224,702, from which 3,550 tons of copper, worth £319,381, had been made.

Between 1911 and 1918, the Cape Copper Company had done a little prospecting at Mosaboni, Laukesra and Surda, localities lying eight to ten miles to the south-south-east of Rakha, on the continuation of the belt in that direction, and in 1920, the Cordoba Copper Company, under the management of John Taylor & Sons, took an option on the Mosaboni area of some 20 square miles from the Cape Copper Company. This option was exercised in 1924, after the Main and Western Lodes at Mosaboni had been developed to a depth of 500 feet, and the existence of considerable ore reserves proved. In 1924, the Indian Copper Corporation of today came into existence as a reconstruction of the Cordoba Copper Company. During this period other prospecting ventures were made in the Sideshur-Kandadih area by the North Anantapur Gold Mines Ltd, who partially developed a copper lode at Chapri, an area which had been already bored between 1918 and 1920 by Messrs Tata Sons Ltd in partnership with Gillanders, Arbuthnot and Co. Again, the Ooregum Gold Mining Co. Ltd sank shafts and discovered a lode at Galudih in Kharsawan.

The existing leases of the Indian Copper Corporation Ltd extend over an area of some 24,089 acres and include the producing mines of Mosaboni, Badia and Dhobani; the two former are connected underground while Dhobani lies somewhat further to the west. Its single lode, which is in epidiorite, was reported to be approaching exhaustion in 1950. By October 1953 the Dhobani mine had been closed owing to lack of profitable ore and in the Badia mine at that time there was little evidence that the ore-shoots of the upper levels were continuing to the deeper ones. At the Mosaboni mine, however, some of the ore-shoots have continued downwards though on a diminishing scale, but this tendency had been counterbalanced by the discovery of a new lode, termed the North Badia, which was then persisting downwards in a more satisfactory manner. A circular shaft of 16 feet internal diameter was then being sunk some 3,500 feet out on the hanging wall side to intersect the lode at No. 18 level, and to continue to No. 20 level, a vertical depth of 2,250 feet. It will provide improved ventilation and give better hoisting facilities, allow development in depth and so determine the continuation of the deposits. In this connexion further secondary sinking will eventually be necessary below the 20th level. Two roughly parallel lodes have been worked at Mosaboni, dipping east at approximately 30° to 35° from the horizontal; they have been developed north and south for a total distance of three miles, and by the end of 1950 to a depth of 2,000 feet. The reserves at that time totalled 3,087,195 short tons, with an average copper content of 2.51 per cent. The ore is conveyed by an aerial ropeway for a distance of about 6

miles to Maubhandar, near Ghatsila, where the concentration plant, smelter, refinery and rolling mills of the Corporation are situated. Until 1950, practically all the copper produced was alloyed with zinc and converted into brass, or 'yellow metal' (62 per cent copper with 38 per cent zinc), which was rolled into sheets and marketed entirely in India, the first sheet to be made having been rolled in 1930. In 1950, however, owing to the scarcity and cost of zinc, it was decided to substitute as far as possible the rolling of copper sheet. The Government of India also placed an order with the Corporation for refined copper ingots, to be supplied at the rate of 200 tons per month during the year 1951. Between 1925 and 1950, 6,788,283 tons of ore were raised, mainly from the Mosaboni mine, of an estimated value of Rs 11,91,18,492, or £8,933,886 approximately. From this ore, over the same period, 124,498 tons of refined copper, averaging about 99.5 per cent copper, were made, to be alloyed with zinc and turned into yellow-metal sheets and circles for the Indian trade. The quantity of refined copper produced in the five years ending 1948 averaged 5,967 tons per annum, compared with 6,235 and 6,510 tons during the five-yearly periods ending 1943 and 1938, respectively. The corresponding figures for the brass made from it were 8,185, 8,523 and 9,817 tons. The averages for the two years ending 1950 were 6,502 tons of copper and 8,980 tons of brass.

Chalcopyrite occurs with the lead-silver-zinc sulphides in certain parts of the great ore deposits at Bawdwin, in the Shan States of Burma, particularly at the northern end of the Chinaman orebody and in the Shan, Meingtha and Chin lodes. The copper is recovered in the course of metallurgical operations at Nam Tu and used to be exported to Europe in the form of matte, which, in addition to some 40 to 44 per cent of copper, contained from 25 to 30 per cent of lead and 70 to 80 oz. of silver to the ton. This material was first produced in 1924, and from that time until 1940, 162,241 tons, valued at £3,790,113, had been shipped. It is estimated to have contained 68,510 tons of copper. Production commenced again in 1948 and from that year to the end of 1951, 302 tons of copper matte had been recovered.

The extensive old workings at Baragunda, Hazaribagh district, Bihar, where copper pyrites occurs in lenticular stringers and disseminations in schists and quartzites, have been the scene of various later, unsuccessful ventures. In 1888, the Bengal Baragunda Copper Company produced 218 tons of refined metal here, but J. A. Dunn, in 1942, considered the deposit to be too small and of too low a grade to be worth reopening.

In Madhya Pradesh copper ores occur near Sleemanabad and Niwar, Jabalpur district, as well as in Narsinghpur, 80 miles to the north, on the same strike. The veins at Sleemanabad are in dolomitic limestone, from 6 inches to 3 feet in width, and contain chalcopyrite, tetrahedrite (the sulphantimonite of copper, $4\text{Cu}_2\text{S}$).

Sb₂S₃), galena, pyrite and magnetite, with small gold and silver values. They were prospected in 1904-8 and again in 1937, but full information about their size and extent is lacking.

In Andhra there are extensive old workings near Garimanipenta, in Nellore district, which have yielded a few tons of ore in recent years, but which have not yet been systematically investigated in depth. The Chitaldrug district of Mysore has also yielded small quantities of ore from a felsite which cuts the Jogimaradi Trap at Ingladhahi.

Copper mining probably persisted longer in Rajasthan than in any other part of the Peninsula. Old workings near Khetri, Babai and Singhana in Jaipur are almost continuous for 15 miles, in the upper part of a zone of slates and schists of Ajabgarh age, and are now in a ruinous, waterlogged condition. Nevertheless, A. M. Heron, a former Director of the Geological Survey of India, believes that ore still exists in sufficient quantity to justify reopening and drainage, while proper prospecting offers possibilities of a large, low-grade undertaking. Cobalt minerals are associated with the copper ores at Babai. J. P. David has more recently described the principal ore as chalcopyrite, occurring in slate as 'irregular stringers and disseminated fine grains, sometimes continuous and always lenticular'. Three average samples of such ore from Barkera contained 0.95, 2.10, and 11.8 per cent of copper, respectively, with traces of cobalt in the third. Another series from Akhwali, near Bagor Fort, contained 2.0, 3.3, 3.5, 5.2, and 12.8 per cent of copper respectively, with traces of cobalt and silver. The oxidized ores, malachite and azurite, are associated with larger quantities of silver, usually 3 or 4 oz. per ton of ore. The old workings at Daribo, in Alwar, were re-examined recently, and the grade of ore found in them is stated to have been good enough to warrant further exploration. Much the same remark applies in the case of certain deposits which lie across the south-western boundary of Rajasthan, at Zari and Kalikui, in Ghota Udaipur, Bombay, and from which 6 tons of malachite were obtained in 1948.

There are many occurrences of copper ores in the outer ranges of the Himalayas at intervals from Sikkim in the east to Kashmir in the west. In Sikkim, they were worked extensively in the past by Nepalese miners and were prospected by Burn & Co. of Calcutta, whose operations, however, were suspended during the first world war (1914-18) and never resumed. According to Sir Lewis Fermor, who visited the region in 1911, the more important of a number of orebodies are at Bhotang, 44 miles from Siliguri on the Gangtok road, and Dikchu, about 7 miles to the north of Gangtok, within a mile of the Gangtok-Lachen road, and 75 miles from Siliguri. At the latter place, a clearly defined lode had been opened up along its strike for 200 feet, and proved to have a width of 3 feet, bearing 6.14 per cent copper. The mineralization here is confined to a belt of highly crystalline mica schists with associated gneisses,

which form a boundary zone between the Daling Series and the Sikkim Gneiss. At Bhotang there are two parallel but disturbed ore bands about 3 and $2\frac{1}{2}$ feet thick respectively, separated by some 10 feet of slates, and their content of copper is said to be somewhat higher than that of the Dikchu lode. Later sampling by D. Kerr-Cross revealed that the Dikchu lode as exposed in the adit is of rather higher grade than at Bhotang, but it is in a very isolated locality and extremely difficult of access. These ore bands are interbedded replacement deposits in comparatively unaltered Daling slates. In both cases the chief ore mineral is chalcopyrite and the commonest associated sulphide is pyrrhotite, but galena and sphalerite (zinc blende) are also common, especially at Bhotang. The rarer associates are compounds of bismuth, antimony and tellurium. The telluride of bismuth, tetradymite, Bi_4Te_3 , has been recognized in specimens of copper ore from Sikkim, together with linnaeite, a sulphide of cobalt, Co_3S_4 . Other deposits of similar, interbedded, replacement types occur in the Rhotak valley, at Sirbong, Pachikhani, Pakyong and elsewhere in Sikkim.

To the south of Sikkim, in the Darjeeling district of West Bengal, disseminations of copper minerals in slates and schists of the Daling Series have been mined in the past by primitive methods at several places. Perhaps the most promising of these is at Komai, on the left bank of the Mo Chu, where lenses of rich ore, 2 to 4 feet in width, occur in slates. Little is known of the copper ores of Nepal, beyond the fact that they are associated with the ores of cobalt and nickel, and have been worked on a small scale as at Sikpasorkhani and elsewhere. To the west of Nepal, and in the Almora district of Uttar Pradesh, there are old copper workings near Dewal Thal and elsewhere, but as far as surface indications go they are not particularly promising. Further west still, in Garhwal, there are ancient copper mines at Pokhri and at Dhanpur. J. B. Auden, who visited Pokhri in 1939, was of the opinion that there are probably two lodes in schistose quartzites and chlorite phyllites, forming part of the Garhwal Series in the Chamoli tectonic window, the southern lode having a footwall of sideritic limestone. According to G. N. Dutt, the dolomites and quartzites of the Garhwal Window Series contain a mineralized zone, marked by the presence of the ores of copper and lead, which extends over 60 miles between the Bhagirathi valley in Tehri Garhwal and Dhanpur in Garhwal district, but its economic potentialities have still to be determined. Continuing to the north-westwards, old copper mines have been reported from the Simla Hills, near Solan, as well as from a number of places in the Kulu area. Near Sungam in the Kangra district, small parcels of ore have been obtained from quartz veins traversing Cambrian schist, but very little is known either of this or the other occurrences. Copper-bearing minerals have been found at numerous places in Kashmir and Jammu, and they were mined,

in some instances, in times long past, either from lodes with a quartz gangue which are found in Palaeozoic slates, or from veins which follow planes of brecciation in the Great Limestone. Perhaps the two more important deposits are those of Shumahal, near Hapatnar, in the Kashmir valley, and Gainti, in the Riasi district. At the former locality a slaty band is impregnated with a multiplicity of small veins and lenticular bodies of quartz with chalcopyrite, oxidized at the surface to malachite, azurite and cuprite. At Gainti, chalcopyrite and malachite are distributed along fracture lines in a particular zone in the Great Limestone Series. Where tested, the ore averaged 2.6 to 2.7 per cent of copper. Referring to the copper deposits of Kashmir, C. S. Middlemiss wrote: 'Working them under modern conditions will depend on the opening up of the country by communication lines, on the co-ordination of related industries and on the utilization of by-products.'

In the Punjab of Pakistan, nodules of copper pyrites occur in beds of variegated clay, associated with the Speckled Sandstone of the Salt Range, and especially on the scarp above Katha, in the Shahpur district. From the North-West Frontier Province come reports of 'showings' of ore in Chitral, Waziristan and the Mohmand territory: in 1949, S. Tayyab Ali found a vein of chalcopyrite, $3\frac{1}{2}$ to $4\frac{1}{2}$ feet thick, intimately mixed with quartz and pyrite, near Imirdin in the Lutkho valley. Copper ores were at one time smelted at Jalai Robat, in the Chagai district of Baluchistan, where large heaps of slag still exist. Low-grade ores have been reported from quartz veins in the Kojak-Amran range of the Quetta-Pishin district, and as disseminations in the Tertiary syenites of western Baluchistan.

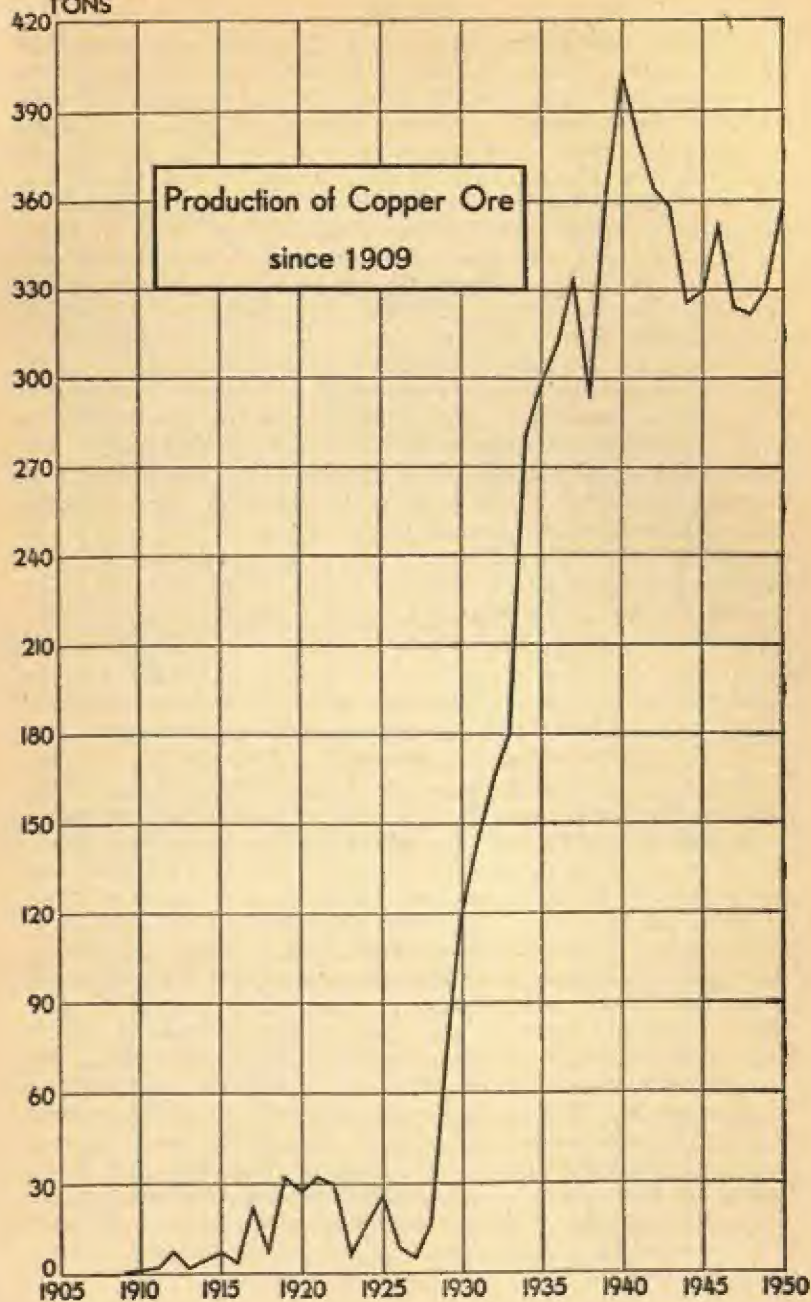
India's imports of copper and brass for the pre-war period 1934-8 averaged 37,281 tons per annum, valued at Rs 2,30,99,723 (£1,732,479), compared with 34,670 tons and £2,276,872 in the quinquennium ending 1932-3. These figures are by no means exceptional, for in earlier years still such imports often cost the country £2½ million and exceptionally more than £3½ million per annum. Two-thirds of the pre-war imports were derived from the United Kingdom and Germany and these supplies ceased on the outbreak of hostilities. Thus, over the war period, 1939-43, imports fell to 19,569 tons, valued at Rs 1,93,73,473 (£1,453,010). To overcome shortages and meet internal munitions' demands, a second copper refinery was erected in India in 1940, where, up to 1943, some 17,000 tons of refined copper were made on Government account, from imported Rhodesian blister copper, part of which entered into the composition of the 13 separate varieties of brasses which were then made in the country for special purposes. During the first post-war year, 1946, imports of brass and copper jumped to 65,777 tons, valued at Rs 7,21,32,282 (£5,409,916), and included in this total are nearly 29,000 tons of high-grade

copper destined for the manufacture of electrical cables and wires in India. In 1950, 41,851 tons of wrought and unwrought copper alone, valued at over Rs 9 crores, were imported. In spite of the fact that there is a tendency for aluminium to replace brass in the manufacture of the traditional Indian cooking and household utensils, the consumption of copper must increase to keep pace with general industrial development.

To meet this existing and growing demand there is an internal, yearly out-turn of but 6,000 to 6,500 tons of copper. If the country is to be independent of external supplies, which may become precarious in times of war, more home production is essential, and it can be met, at least in part, by extending mining operations in the Singhbhum belt. It is perfectly true that the metallic contents of this belt are unusually scattered, but it is not generally realized that it has not been fully prospected. Disseminated as its copper contents are, the actual amount of copper ores within the belt as a whole place it, as J. A. Dunn remarked, amongst the world's greatest mineralized zones, and it is extremely unlikely that the lodes now under exploitation at Mosaboni and Badia are the only profitable ones to be found throughout its entire length. Dunn believed that the lodes in the south-east, in a compact area to the north-west of Baharagora, which have never received any attention, deserve proper investigation, and in his writings various locations are mentioned which offer scope for further work. Amongst others, the whole zone of schists forming the centre of the Surda ridge, honeycombed as it is with ancient workings, should be systematically sampled with a view to mining on a large scale by open-cast methods.

The copper ore deposits of Rajasthan and of Sikkim have promising possibilities, but in both instances expensive exploratory work is needed, especially in the former case. Little is to be gained by surface examinations alone, or, for that matter, from opening up ancient workings unless they are to be extended, for the old miners of past generations were adepts in removing every scrap of visible ore from them. Depths unattainable by them must be reached and explored, either by drilling, or, better still, by mining and drainage, before any proper evaluation is possible. Experience in the successful search for other minerals under similar conditions proves that this demands both time and capital. Such undertakings are not for the individual or for small syndicates; they are more properly ventures to be financed and technically controlled by the State, or by large-scale enterprise. It is as well to recall here that all the early attempts to mine copper ores in Singhbhum were profitless failures, until the Geological Survey of India carried out a diamond drilling campaign along the copper belt during the years 1906-8, and, in so doing, redirected private enterprise into what has since become a well-established mining and metallurgical industry.

THOUSAND
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LEAD

Although galena, the sulphide of lead, sometimes accompanied by the carbonate, cerussite, PbCO_3 , has been found at many places in India and Pakistan, and although at some of these it was mined on a small scale to supply local needs in times past, the vast majority of these occurrences are of mineralogical interest only and far too limited in extent to offer hope of profitable exploitation. Reference has already been made under COPPER to the lead ore deposits of the Dhadka neighbourhood, in Manbhum, Bihar, but prospecting operations in 1904 and 1905 proved them to be but sporadic and superficial and no continuous lode was found. A re-examination by A. K. Dey in 1934-5 confirmed this conclusion. On many occasions after 1850 until the early years of the present century, various deposits scattered across Bihar were opened up by syndicates and companies without any success. 'It is perhaps possible that in some cases the capital available was too limited,' writes J. A. Dunn, 'but the author is of the opinion that failure was entirely due to the absence of any deposits of reasonable size.' A thorough trial of a deposit at Beldi, in Manbhum, was made by Messrs Mackinnon Mackenzie & Co. in 1904-5. The ore obtained was railed to Howrah and smelted in a small furnace at Shalimar, but after yielding $91\frac{1}{2}$ tons of lead, 4,716 oz. of silver and 86 grains of gold, the deposit petered out in depth. In the absence of new discoveries, therefore, lead mining is unlikely to be established in Bihar, and unfortunately, the outlook in most of the other States is, at present, equally unpromising; many of the known deposits have been re-examined in recent years and the reports on them have concluded monotonously with the words 'of no economic value'. During 1951-2 lumps of galena were found in a field at Metri some 25 miles north-west of Bellary in Mysore by workmen engaged in the collection of *kankar*. The occurrence was opened to a depth of 15 feet and about 15 tons of galena, assaying 82.53 per cent lead, 12.77 per cent sulphur and 2.71 oz. silver, were recovered, but no vein had been met with when prospecting was abandoned owing to lack of funds. Of extra-peninsular occurrences, E. R. Gee considered that the galena-bearing lodes of the Kulu area and particularly those near Jhari, Saughthan, Uchich, and Khanor Khud, which in some cases also carry copper minerals as well as gold and silver values, are deserving of detailed investigation. He also mentions the galena occurrences of the Great Limestone of Riasi, in southern Kashmir, and states that, though they have been explored, the results were not available, except for 1.5 tons of galena reported to have been produced in Kistwar in the district of Doda, Kashmir. Full details of all the known lead ore localities are obtainable from the published summaries of the mineral resources of the various States and from the *Directory of the Economic Minerals of Pakistan* (1950).

In the ancient mines of Zawar, Udaipur, Rajasthan, reopened by the Geological Survey of India during the last war, there is an exception to this depressing record, for here mixed ores of lead and zinc are being won by the Metal Corporation of India Ltd who, since 1945, have raised 30,978 tons of ore and smelted them at their Tundoo works, on the Jharia coalfield, for a return of 1,464 tons of 99.9 per cent lead, valued at Rs 17,88,734. For the year 1951, a further 859 tons of metallic lead, valued at Rs 15,00,000, have to be added to this total. A description of the mines is to be found under ZINC.

With this introduction, the story of the lead, silver and zinc industries of the former Indian Empire centres entirely around the history of the discovery of the great ore deposit of Bawdwin, in the Shan States of Burma, and of the expansion of mining and metallurgical enterprise there. This mine, unique of its kind in the world, was originally opened by the Chinese, perhaps in the early part of the fourteenth century, and it supplied large quantities of silver to their exchequer until its abandonment in the middle of the nineteenth century, on account of deep drainage difficulties and the outbreak of the Mohammedan revolt in Yunnan. The vast heaps of rich lead slags, left after the silver had been extracted from the ores, attracted attention in the early days of the present century, and from 1909 onwards yielded large tonnages of metallic lead until they were exhausted. European exploitation dates from 1902, but, as is so often the case, the early ventures were not encouraging, until exploration below the level of the old workings resulted in the discovery of the Chinaman orebody in 1912. In 1919, the Burma Mines Ltd was acquired by the Burma Corporation Ltd, which had its headquarters in Rangoon. The capital of the Corporation was Rs 18,00,00,000, in Rs 10 shares, of which 1,35,41,689 were issued, and in May 1935 the capital was changed to Rs 18,00,00,000 divided into 2,00,00,000 shares of Rs 9 each.

In the neighbourhood of Bawdwin, a series of rhyolitic tuffs, lava flows and breccias, with coarse felspathic grits, of early Palaeozoic age, has been intensely crushed and disturbed by overthrust faulting. Within this shear zone, intimately connected with the faulting, lies a well-marked ore channel, at least 8,000 feet long and 400 to 500 feet wide, and within this ore channel again, so far as it has been developed, three major orebodies, once united, but now separated by post-mineralization cross-faulting, have been found. They are of approximately equal length, with the Chinaman orebody in the centre; the Shan lode, from which it was torn and thrown approximately 700 feet to the south-west by the Yunnan fault, lies to the north, while the Maingtha lode, at its other end, has been moved 1,200 feet to the south-east by the Hsenwi fault. The ores themselves have been deposited from solutions which, there is some reason to suppose, originated from a deep underlying

granite magma and, finding easy passage through the shear planes of the intensely crushed overthrust zone, metasomatically replaced the minerals of the congenial rhyolitic tuffs. The typical ore is a fine-grained, intimate mixture of galena and sphalerite with chalcocopyrite in places; it is frequently banded and often shows signs of crushing. The rarer ore minerals include pyrite, arsenopyrite, löllingite, gersdorffite, cubanite, tetrahedrite, bourmonite, boulangerite and pyrrargyrite. In the shallow oxidation zone, near the surface, cerussite, anglesite, pyromorphite, melaconite, chalcocite, native copper, malachite, azurite, calamine, massicot, goslarite and brochantite have been found. The central orebody—the Chinaman—is a huge, lenticular replacement, averaging about 50 feet in width with a maximum of some 140 feet of solid lead-zinc sulphides. It has been developed for over 1,000 feet and to a depth of more than 1,200 feet, where the mineralized zone ceases at the base of the rhyolitic tuffs. The Shan lode averages about 20 feet in thickness and is characterized by its high copper values at certain levels. The Maingtha lode, discovered in 1929, is also about 20 feet thick, and whilst its upper portion above No. 6 level is lead-zinc-copper ore, similar to that of the Chinaman orebody but with lead and zinc values lower and copper values higher, and about the same silver ratio, below that horizon copper ore is found with very little lead or zinc, but with profitable values of nickel and cobalt, apparently in a definite ratio of nickel 2: cobalt 1, though even here, the silver ratio remains the same as in the rest of the ore. To the north of the Bawdwin fault (the most important of the pre-mineralization disturbances of the area), and some 2,000 feet from it, there is a flat-dipping vein of chalcocopyrite in rhyolite, known as the Chin lode.

The major axis of the orebody as a whole has a general pitch to the north. In the Chinaman and Shan lodes the dip is high to the west with a tendency to turn over in the lower levels, whereas in the Maingtha section it is to the east. For the most part the hanging wall is well-defined and regular, but the foot wall is ill-defined with no clean boundary: mineralization becomes sparser in this direction and often continues considerable distances before barren rock is reached. As the values gradually decrease, the mining limit of the stopes is arbitrarily fixed by what is considered to be payable ore at the time. For some years it was defined as ore containing not less than 20 per cent combined lead and zinc, and, if lowered, will add considerably to the reserves of low-grade ore. On both sides of the solid ore-core, but more generally towards the east, thin parallel bands of ore occur in the mineralized tuffs of the ore channel, but these branch veins unite, as a rule, with the solid ore in depth. In the following table the changes in the distribution of the silver, lead, zinc and copper contents of the three main orebodies are shown as their depth from the surface increases.

ASSAY VALUES OF BAWDWIN ORES AT VARIOUS DEPTHS

OREBODY AND LEVEL	SILVER oz.	LEAD %	ZINC %	COPPER %	SILVER RATIO	
					to LEAD	to ALL METALS
Chinaman No. 2	19.4	24.1	20.9	0.10	1 - 1.24	1 - 2.32
" No. 4	31.7	31.8	22.8	0.70	1 - 1.03	1 - 1.70
" No. 6	23.0	28.1	14.2	0.50	1 - 1.22	1 - 1.85
" No. 9	14.6	23.0	9.1	0.30	1 - 1.58	1 - 2.22
Maingtha No. 2	13.3	15.4	11.4	1.23	1 - 1.16	1 - 2.11
" No. 4	18.3	24.0	12.7	1.31	1 - 1.31	1 - 2.08
" No. 6	13.9	17.4	6.4	1.60	1 - 1.25	1 - 1.83
" No. 9	5.0	7.3	1.4	3.50	1 - 1.46	1 - 2.44
Shan No. 2	13.3	24.6	6.8	0.70	1 - 1.85	1 - 2.41
" No. 4	23.7	14.8	10.2	8.20	1 - 0.62	1 - 1.40
" No. 6	19.1	21.0	13.1	2.20	1 - 1.10	1 - 1.90
" No. 9	21.3	30.3	10.0	0.35	1 - 1.42	1 - 1.90

'For all practical purposes,' wrote E. L. G. Clegg, a former Director of the Geological Survey of India, 'the mine is now fully developed. In depth the mineralized zone ceases at the base of the Bawdwin rhyolite series, as was originally predicted by Coggin Brown.'

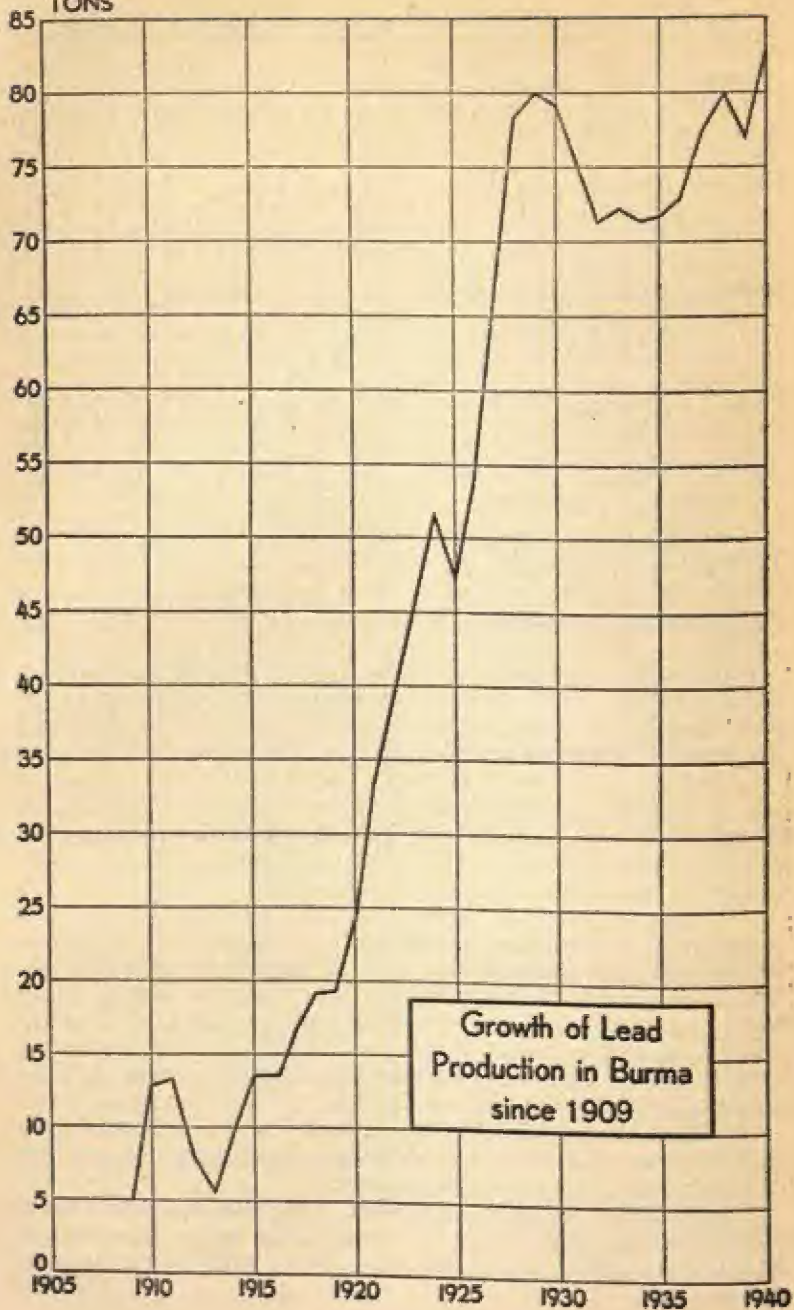
The main way into the mine is by Tiger Tunnel, 7,250 feet long, 653 feet below the zero level at Bawdwin and corresponding to the sixth level of the mine. It is masonry-lined, double-tracked from the portal to Marmion's shaft and is the chief haulage and drainage level; all ore, as mined, is raised or lowered to it, to be trammed out by electric locomotives to the storage bins at Tiger Camp. Marmion's shaft is sunk from the surface at Bawdwin, through the country rock on the west of the Shan orebody, and is 1,741 feet deep, with 14 levels at intervals of 120 to 150 feet.

The mine is connected with the smelter at Nam Tu, 13 miles distant, and with the Burma Railways at Nam Yao, 547 miles from Rangoon, by the Corporation's own railway, 45 miles in length. The milling and flotation plant had a capacity of 800 to 1,000 tons per day, and there were five blast furnaces with their attached roasters, as well as the refinery in which the silver was separated from the lead. Hydro-electric power was obtained from the Corporation's plant at the Mansam falls on the Nam Yao river.

In the following table the total quantity of lead extracted from the Bawdwin ores in Burma, from the commencement of operations in 1909 up to the end of 1941, is shown.

These figures include antimonial lead, the average annual production of which for 1934-8 was 1,269 tons. The highest annual production was attained in 1929, with 80,233 tons of metallic lead.

THOUSAND
TONS



PRODUCTION OF LEAD AT NAM TU, 1909-41

PERIOD	TOTAL TONNAGE	STERLING VALUE
1909-13	45,550	632,505
1914-18	73,817	1,792,345
1919-23	161,902	4,405,718
1924-8	297,715	8,340,471
1929-33	377,995	5,887,169
1934-8	374,780	6,218,633
1939-41	229,895	3,715,342*
TOTAL	1,561,654 tons	£30,992,183

* Value for 1941 is estimated.

The following table shows the ore position at the Bawdwin Mine on 1 July 1939, the last detailed figures available to the authors: at that time the total ore reserves amounted to 3,610,803 tons containing 17·7 oz. of silver, 23 per cent of lead, 13·8 per cent of zinc and 0·92 per cent of copper. They also included approximately 280,000 tons of copper ore. In 1942, the year of the Japanese invasion, the reserves were 3,130,199 tons with 15·1 oz. of silver, 19·5 per cent of lead, 12·1 per cent of zinc and 0·84 per cent of copper.

ORE POSITION AT THE BAWDWIN MINE ON 1 JULY 1939

	TONS	AVERAGE ASSAY VALUES			
		Silver oz.	Lead %	Zinc %	Copper %
Chinaman Orebody ..	6,897,859	21·1	25·0	16·1	0·40
Shan, etc., Lodes ..	2,454,270	17·8	21·5	10·7	2·09
Maingtha Lode	1,617,121	13·0	15·2	9·0	1·97
Chin Lode	20,500	1·9	nil	0·5	8·41
TOTAL (Proved & Probable)	10,989,750	19·1	22·7	13·8	1·05
Excess tonnage *	286,417	8·9	13·3	3·8	nil
EXTRACTED	11,276,167	18·9	22·5	13·6	1·02
	7,668,222	19·4	22·3	13·5	1·07
RESERVE IN MINE	3,607,945	17·7	23·0	13·8	0·92
Ore Stocks	2,858	14·1	19·0	10·5	0·65
TOTAL ORE RESERVES ..	3,610,803	17·7	23·0	13·8	0·92

* Excess tonnage is from completed stopes.

Disturbed conditions in Burma following the war have hindered the large-scale resumption of base metal production at Nam Tu, but towards the end of 1948 it became possible to dispatch fuel supplies there again, and with them to commence smelting accumulated ore stocks and to send the finished metal to Rangoon for sale. The production in 1948 was 264 tons of lead, which increased to 846 tons in 1949. It was stated in November 1951 that no forecast could be made as to when production from newly mined ore could be restarted, as this depended on security conditions in Burma and on the restoration of adequate, through, railway traffic between Rangoon and Nam Tu. At the same time the sale of the undertaking was announced to a new Company, to be known as Burma Corporation (1951) Ltd, in exchange for 3,159,730 fully paid shares of Rs 10 each in that concern. The Government of the Union of Burma have also agreed to subscribe by instalments in cash, at par, for 3,159,730 shares of Rs 10 each, in the capital of Burma Corporation (1951) Ltd, thus obtaining an equal participation in that Company. It can only be hoped that by this means the whole industry will be rehabilitated and brought once again to its full productive capacity and, further, that the association of the State with it will soon lead to the development of similar mineral deposits in other parts of the Union.

During the year ended 30 June 1952, the available labour force was increased from 497 to 1,058 men, employed solely on repairs and preparation for the resumption of mining, the initial target being 8,000 tons of ore per month, for which a force of 1,600 is required. Rehabilitation of the Man-sang Falls hydro-electric power station was in progress, and during the year sales of products obtained from the processing of surface stocks amounted to 4,798 tons of refined lead, 231,670 oz. of refined silver and 3,251 tons of other products. The remaining surface stocks were estimated, to yield ultimately 1,400 tons of refined lead, 180,000 oz. of refined silver and some quantity of other products.

A small indigenous lead industry existed in Mawson, one of the minor States in the Myelat division of the Southern Shan States, from the fourteenth century until it was extinguished on the annexation of Upper Burma by the British, in 1886. Several more or less parallel ore-bearing zones occur in the local Plateau Limestone, and in older rocks of Ordovician age, which are traceable by means of old workings and slag heaps. The Shan miners obtained the lead ores mainly from clay-filled cracks and fissures in the limestones, but extensive modern exploration has, up to the present time, only succeeded in locating two small orebodies. One of these was developed at Bawzaing by a European company, where the probable ore reserves at the end of 1930 were stated to be 185,400 tons, containing 7 per cent of lead with 13 oz. of silver. The mine was closed in that year and has not been reopened. For the five years ending 1928 a total of 25,440 tons of lead ore and slags,

valued at £27,940, were produced in the Southern Shan States, compared with 434 tons for the previous period of equal duration. During the years 1935 to 1937, 9,542 tons of ancient lead slags were collected and exported.

The amount of lead imported annually into India is normally between 7,500 and 8,000 tons, but for the three years 1949 to 1951 the annual average increased to 10,004 tons, valued at Rs 1.6 crores approximately.

ZINC

Ancient zinc mines, reputed to have been discovered in the fourteenth century and to have been closed during the great famine of 1812-13, exist near Zawar, 15 miles due south of Udaipur, Rajasthan. The old workings all lie within a radius of 3 miles of Zawar; the principal ones, according to A. M. Heron, stretching for about three-quarters of a mile, to form a vast open-cast in brecciated limestone of Aravalli age, averaging 80 feet in width and 40 feet in depth, with irregular, cavernous excavations of unknown extent in its bottom. No traces of the ore-bearing minerals were visible at the surface, but the clinker which still filled the old retorts from which the ore was distilled, and which are still to be found in countless numbers in the vicinity, contained varying quantities of zinc and lead.

During the last war, owing to the shortage of lead and zinc in India as a result of the loss of Burma, the Government decided to reopen the Zawar mines under the direction of the Geological Survey of India, and five adits were driven into selected sites in the Mochia Magra ridge, but, as it became evident that no supplies of lead or zinc could be obtained from this source during the war, the Government sold back the mining rights to the Mewar State for about one quarter the cost of the development work. In 1945, the State leased the area to the Metal Corporation of India Ltd, which by the end of 1950 had raised 31,812 tons of ore. From this, 4,358 tons of hand-dressed lead concentrates were obtained, railed to the Corporation's works at Tundoo, near Katrasgarh, in the Jharia coalfield of Bihar, and smelted for a return of 1,464 tons of 99.9 per cent lead, valued at Rs 17,88,734. A flotation plant was installed in May 1950 which separated 655 tons of zinc concentrates during the year, analysing 48.76 per cent zinc, 4.23 per cent lead and 0.21 per cent cadmium. The zinc concentrates are shipped abroad for reduction, on the understanding that half their metallic contents are returned to India. It is the present aim of the Corporation to crush 175 to 200 tons of mine ore daily, and this is estimated to yield some 15 tons of lead concentrates and 25 to 30 tons of zinc concentrates per diem.

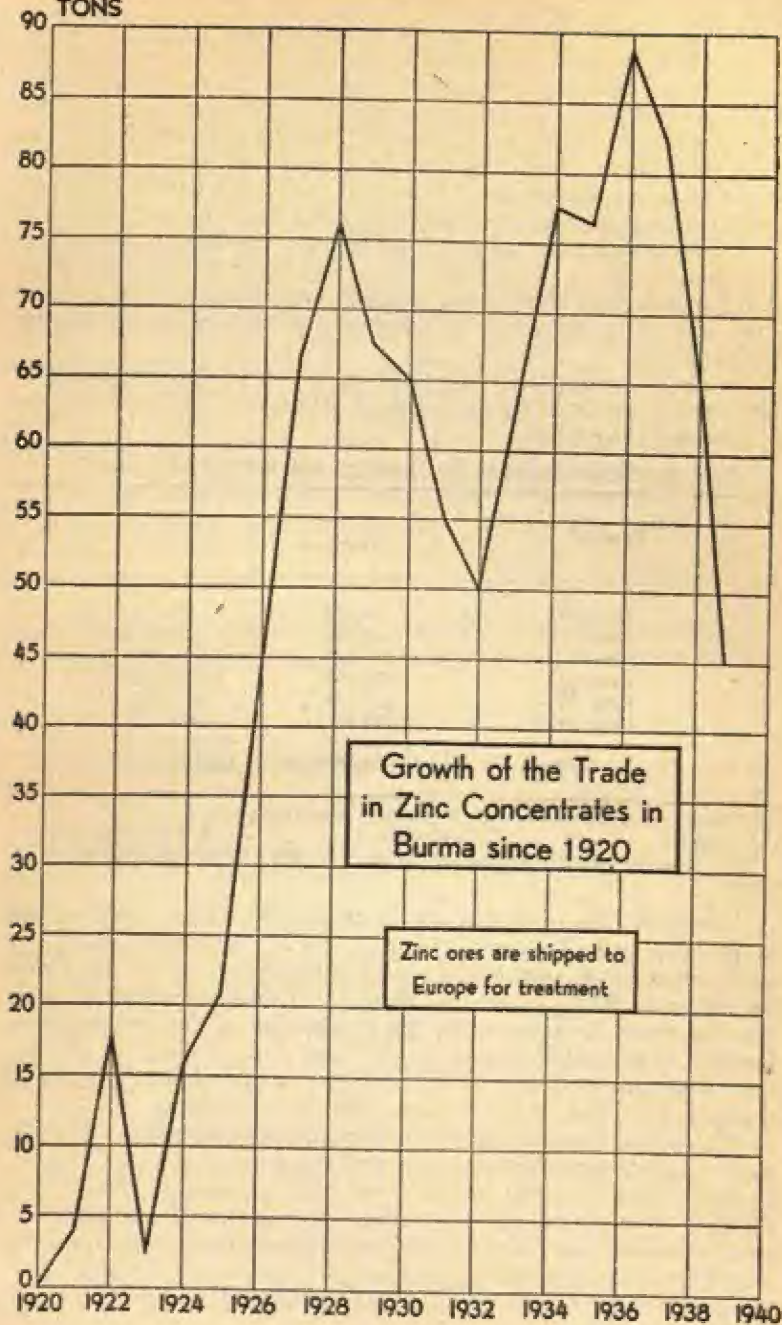
During the year 1951, the output of zinc concentrates from the flotation plant was increased to 2,110 tons, averaging zinc 49.85 per cent, lead 5.10 per cent and sulphur 28.7 per cent. At the

same time 1,783 tons of lead concentrates were produced, averaging lead 72.5 and zinc 7.04 per cent as far as the flotation product was concerned, but this tonnage also included a quantity of hand-dressed lead concentrate assaying lead 45.48 and zinc 12.14 per cent, as distinct from the flotation product. The smelter at Katrasgarh treated 1,770 tons of lead concentrates for a return of 859 tons of metallic lead, valued at Rs 15 lakhs. Of the zinc concentrates 1,965 tons, valued at Rs 6,50,000 (c.i.f. destination), were exported for treatment. Plans are in hand to increase the mill throughput to 500 tons daily. The principal ores are zinc blende and galena, associated with pyrite and some other sulphides, as disseminations and replacement bodies in dolomitic limestones, interbedded with phyllites and quartzites in a pitching overfold. In the existing workings at Mochia Magra, which occupy but a small portion of the mineralized zone, D. Kerr-Cross, in March 1949, estimated a reserve of 442,000 tons of ore, averaging 11.58 per cent lead and 10.51 per cent zinc, within a depth of 50 feet, over a width of 120 inches for a length of 1,329 feet. The mineralization appears to be extensive beyond these limits. The mineralized zone found later is said to be from 85 to 100 feet in width and, according to B. Srikantan and M. R. Subramanyam, it extends downwards beyond a depth of 130 feet below the level of the 6th adit. At the end of 1951, the ore reserves were stated to be of the order of 700,000 tons with lead 5.25 per cent and zinc 7.25 per cent, with 2 million tons of second-grade ore assaying lead 1.9 per cent and zinc 3.8 per cent and a probable reserve of 8 million tons of low-grade material containing a minimum of 3 per cent metal. Geological research has already shown that the rocks in which the orebodies occur may be expected to continue downwards to considerable depths without much change, and as the mineralization has taken place through a series of cleavage planes, formed in the course of widespread regional metamorphism, there is no theoretical reason why it should die out in depth though the character of the minerals in the lodes themselves may change gradually. The area mined by the ancients was much more extensive than the small section so far developed, and until the ridge running south from the old city of Zavar, the hills about Zamarmala, the hills known as Sonria and Rupria west of the Tiri river, as well as Balria Hill east of that river, have been fully examined, the full possibilities of the district cannot be said to be known.

The zinc ore deposits in dolomite at Darabi, Jammu, Kashmir, contain but meagre reserves of a few thousand tons of blende, while little is yet known of the deposits near Tiplin in Nepal.

The Burma Corporation Ltd used to produce large quantities of zinc concentrates from its milling plant at Nam Tu. It has been stated under LEAD that the ores of the Bawdwin mine are intimate intergrowths of argentiferous galena and zinc blende with small

THOUSAND
TONS



Growth of the Trade
in Zinc Concentrates in
Burma since 1920

Zinc ores are shipped to
Europe for treatment

quantities of chalcopyrite, and the reserves of ore still known to be in the mine in 1941, amounting to no less than 3,130,200 tons, are estimated to contain 12·1 per cent of zinc. As the table shows, a total of 985,963 tons of zinc concentrates, averaging over 50 per cent of zinc and valued at £4,853,971, had been produced between 1914 and 1940. Regarding the distribution of the zinc contents in the Chinaman orebody at Bawdwin, while the values remained fairly constant around 20·5 per cent zinc, down to and including No. 4 level, with some tendency for them to predominate over the lead content on the foot wall, below this horizon the zinc values of the mixed sulphides exhibit a progressive decrease from level to level, until they form only 9·1 per cent of the ore at the bottom of the mine.

In the following table the total quantities of zinc concentrates produced or exported by the Burma Corporation Ltd are arranged in periods of five years.

ZINC CONCENTRATES, PRODUCED OR EXPORTED, 1914-40

PERIOD		TOTAL TONNAGE	STERLING VALUE
1914-18*	..	11,974	27,274
1919-23†	..	24,198	122,435
1924-8‡	..	206,702	1,881,727
1929-33‡	..	273,426	1,072,523
1934-8‡	..	358,531	1,427,234
1939-40‡§	..	111,132	322,778
TOTAL	..	985,963 tons	£4,853,971

* Three years only. No exports in 1917 and 1918.

† Exports.

‡ Production.

§ Two years only.

These concentrates averaged about 51 per cent zinc, 6 per cent lead and 9 oz. silver.

The peak year of output was in 1935 when 78,590 tons, valued at Rs 37,99,358 (£284,951), were produced, although the 73,552 tons turned out in 1937 had a considerably higher value, the actual figures being Rs 54,40,421 (£408,031). There have been times in the history of the mine when the production of zinc concentrates became unprofitable, owing to the low prices ruling for spelter, and was continued only because of contractual obligations and of the spread it afforded for transport and fixed charges.

These zinc concentrates were shipped almost entirely to Belgium until 1939, though Germany also received a share of them. Later, they were transferred to Australia until the Japanese armies overran Burma. A proposal to smelt the concentrates at Jamshedpur, and to recover their sulphur contents in the form of sulphuric acid, was abandoned some years ago, though it would have been of great advantage to the development of India's chemical and metallurgical

industries at the time and is worth the serious consideration of both countries in the future. Another proposal to recover metallic zinc in the Toungoo district of Burma, by means of hydro-electric power generated on the Yunzalin river, shared the same fate.

India consumes large quantities of zinc, particularly for the manufacture of brass and other alloys, and for the galvanizing of corrugated steel sheets and numerous other iron and steel products. The metal is also used alone as the cylinder container of dry batteries for electric torches and for many forms of zinc die-castings. The oxide of the metal is a valuable pigment in the paint and colour trade, the sulphide is a constituent of lithopone, and there are many other important industrial applications of various zinc compounds. The imports of metallic zinc alone into India have increased threefold in the past fifteen years, and now exceed 33,000 tons per annum. Thus, in 1950, they totalled 33,440 tons and cost Rs 5,23,02,223, while the average for the three years 1949 to 1951 was 29,080 tons, valued at Rs 5.09 crores. The revival of Rajasthan's ancient zinc mining and smelting industry is thus a matter of urgent national consequence worthy of all the encouragement and assistance that the Republic can supply. The first action needed is further intensive development of the Zawar deposits, for until much larger reserves of the better grades of ore are proved than those known at the end of 1951, plans for the establishment of a zinc reduction plant in India, entirely dependent on the supply of such ores, can only be regarded as premature.

TIN

The oxide of tin, cassiterite, has been found at a number of places in the Hazaribagh, Ranchi and Gaya districts of Bihar, but none of the occurrences appear to possess economic importance, though as long ago as 1849 tin ore was being smelted in village iron furnaces at Purgo, in the Palganj estate near Parasnath. According to Sir Lewis Fermor, there is here a thin layer of cassiterite granulate, up to 6 inches thick and containing 30 to 50 per cent of the tin ore, in a much thicker band of microcline granite which itself contains scattered grains of cassiterite. Mallet described an attempt made about 1867 to work this deposit and states that the ore formed three or four lenticular beds in gneiss, seldom more than a foot or two across, but in places reaching a width of 13 feet. The lateral extension was about 60 feet, nearly parallel to the foliation of the gneiss. The beds were followed to a depth of some 60 feet, in an inclined shaft, before work was stopped by decreasing values and flooding. Another venture was made in 1891-2, when an inclined shaft was sunk on the ore band to a depth of 614 feet, but below 568 feet the ore band had disappeared. It had ranged in thickness from 6 to 18 inches and a sample from a full section of the working, consisting of 15 inches of ore band and the remainder

wall rock with disseminated tinstone, yielded 1.87 per cent of tin. Other samples assayed 2.1 to 6.2 per cent of the metal. The mine was eventually abandoned through lack of funds. The occurrence was examined again in 1909-10 and the surface portion worked with the production of 6 cwt of tin, in the two years 1909 and 1910; a further 14 cwt were made in 1915. The prospects of reopening this tin mine are not encouraging. The other three occurrences of cassiterite in Hazaribagh are of scientific interest only: a few crystals have been found in a lens of granite enclosed in mica schists at Simratanri, small grains occur in a dyke of lepidolite granite at Pihra and, again, in a granulite at Chappatand. The mineral has also been reported from a pegmatite intrusive into granulite, near Silli, Ranchi district; from Dhanras Pahar, in the Deo Raj estate of Gaya district, and in a vein associated with wolfram, a few miles north of Chhakarband in the same district, where it is said to be present to the extent of 1.5 per cent. Recently there has been an output of 7 tons of cassiterite from pegmatite in the hills to the north of Paharsingh in Ranchi district. Outside Bihar, cassiterite has been found, but again only in insignificant amounts, in a tourmaline pegmatite at Hosainpur, Palanpur, Bombay, where it is associated with gadolinite, a silicate of beryllium, yttrium and iron, and in alluvial deposits of streams draining the northern part of the Kapatgod range, near Dambal, Dharwar, Bombay. There are no recorded instances of the occurrence of tin ore in Pakistan.

The earliest reference to the occurrence of tin in Burma was made by Ralph Fitch in 1599, who remarked that on his journey from Pegu to Malacca, he passed by 'many of the ports of Pegu, as Martauan [Martaban] and the Island of Taui [Tavoy], from whence commeth great store of tinne, which serueth all India'. The cassiterite deposits of Burma have indeed been worked from a remote antiquity, especially in the lower part of the Tenasserim division. The granitic mountain ranges of Lower Burma are but the northern continuation of the same rocks which have yielded the rich tin ore deposits of Malaya and of western Thailand. The region in which the Burmese ores occur corresponds with that described in the case of TUNGSTEN, for wolfram and cassiterite are most intimately associated and of identical origin.

The tin- and wolfram-bearing localities of the Mergui district, in the extreme south, lie in the Palaw and Palauk, the Mergui and Tenasserim and the Bokpyin and Victoria Point townships, of the north, central and southern portions respectively. The tin mines are situated principally on the mainland, in two parallel mineralized zones, but another belt traverses Lampi and adjoining islands in the Mergui archipelago. The ore zones are more or less parallel to, and genetically connected with, the granitic intrusions, and generally lie at or near their junctions with the sedimentary rocks of the Mergui Series. The tin ore occurs as a constituent of

decomposed granite and greisen, associated with tourmaline and muscovite; in quartz veins, up to ten feet thick, with wolfram and one or more members of a sulphide suite of minerals; and in narrow quartz veinlets and stringers forming stockworks in rocks of the Mergui Series. Surface ore-deposits of both eluvial and alluvial origin are common, but while wolfram and cassiterite occur in the former, the tin ore is found alone in the latter, as it is resistant to the processes of disintegration and decay which remove the wolfram before it reaches the true water-sorted alluvials. All the known occurrences were listed by the late Rao Bahadur Setu Rama Rao in 1930, who also indicated the more promising areas which then remained to be prospected. By 1939, there were 219 separate mines producing tin ore in the Mergui district, in addition to 34 which were yielding mixed tin and wolfram concentrates. The vast majority of them were small Chinese-leased concessions from which a few tons of ore were won by ground sluicing in the rainy season, and only 9 of the whole total gave over 50 tons per annum. The more important areas lay around Palaw, Yamon, Theindaw, Thabawleik, Khechaung and Karathuri. Before the occupation of Burma by the Japanese in 1942, modern tin dredging was carried on by the Tavoy Tin Dredging Co. Ltd at Theindaw, from 1936; the Thabawleik Tin Dredging Co. Ltd at Thabawleik, from 1928; the Lenya Mining Co. Ltd at Yamon, from 1939, and the Tavoy Tin Dredging Co. Ltd at Karathuri, from 1938. The Thabawleik dredge alone had already, at times, produced over 600 tons of concentrates per annum; after the war it commenced operating again in 1947. The tabulation of tin ore statistics was commenced by the Geological Survey of India in 1898, and from that time until the end of 1939 the Mergui district had given a total of 22,311 tons of tin ore, averaging about 72 per cent of tin. In addition to this, between the years 1910 and 1922, 1,187 tons of metallic tin were made in small Chinese furnaces and exported. The maximum annual output was reached in 1939, when 2,017 tons of concentrates were won.

North of Mergui lies the Tavoy district where geological conditions are much the same as those prevailing in Mergui. Granite intruded into a series of sedimentary rocks forms the cores of its mountain ranges; quartz veins and pegmatites carrying wolfram and cassiterite and more rarely molybdenite, bismuthinite and bismuth, together with a large variety of sulphides, cut through them both. These minerals occur also in the eluvial deposits of the hill slopes, where ore-bearing veins are undergoing degradation, and in the coarse, unsorted debris at the heads of the flatter valleys. Cassiterite is found too in the water-sorted alluvial deposits, the gravels and sands of the lower portions of the streams, both of Recent and sub-Recent ages. Though Tavoy is primarily a wolfram-producing district, there are places within its densely forested 5,308 square miles which are richer in cassiterite than

others, and it is from these and from the gradual extension of dredging operations that increased production has been and will be obtained. The Tavoy Tin Dredging Co. Ltd, the earlier activities of which were briefly outlined in the second edition of this book, continued later to operate three dredges in the Taungthonlon area where there are wide placer deposits, old river terraces and shallow leads of earlier stream channels containing tinstone. Another dredge of the same concern worked in the tideway of the Heinze Basin, on the northern coast of the district, and in 1939 won 571 tons of concentrates from the sea bed. Following the Japanese evacuation, two of its dredges in Tavoy and one in Mergui had been reconstructed by 1949. On the flats to the south of the Heinze Basin, the dredge of the Heinze Burma Tin Co. Ltd was installed, while yet another was recovering the tin ore from the alluvial deposits of the Khamaunghla valley.

Amongst important mines producing mixed concentrates were Hermyingyi, where over 60 different veins have been exploited; Kanbauk, with an important vein series and thick detrital and alluvial deposits of considerable extent; and Hpolon Taung, where the Anglo-Burma Tin Co. Ltd works rich horizons occurring in unusually thick deposits of sands, gravels and boulders, by hydraulic methods. In addition to these and other properties, well equipped with plant both for vein and hydraulic mining, there are in Tavoy many areas still worked by ancestral Chinese methods. The Tavoy field will always remain predominantly a wolfram-producing one: thus, of a total of 203 concessions in 1939, 93 yielded wolfram, 76 gave mixed concentrates and 34 tin ore. Between the years 1898 and 1939, the tin ore production of the Tavoy district was 42,249 tons, the maximum annual total being 3,360 tons in 1939. During the years 1912 and 1913, 128 tons of metallic tin were also exported from the district.

Small quantities of tin ore have also been won, since 1916, in the Amherst and Thaton districts, and in the Yamethin district of Upper Burma, since 1936, the total outputs recorded being 618, 381 and 118 tons, respectively. The geological surveys of these districts have not been completed, but metamorphic aureoles are known to exist around the intrusions of the local granites, of the same age as those of the Tavoy and Mergui districts further south, carrying tourmaline and veins of tourmaline micro-pegmatite which in places bear quartz stringers with cassiterite. The occurrences in Thaton lie at the ends of the wolfram-bearing areas of the Zingyeik range. In Amherst, alluvial ore has been won on Belugyun Island, at the mouth of the Salween river, and from both eastern and western flanks of the Seludaung range. The mountainous tracts of both these large districts are covered with dense forests and are very inaccessible, as there are no communications except primitive tracks, away from the larger rivers and their plains. Until they have been geologically mapped and prospected,



DREDGING FOR TIN ORE IN THE TAVOY DISTRICT, BURMA



it is premature to rule them out as potential tin-mining regions of little value. In Yamethin too, the mines lie in the forested mountains along the steep scarps of the Shan plateau, mainly around Hmanpyataung, and such rough tracks as do exist are due to the efforts of the mining community itself. This region borders the dry zone of Burma, and water for mining and concentration purposes is often difficult to obtain.

The output of the Southern Shan States is derived almost entirely from the important Mawchi mine in Karenni, where biotite granite has invaded a series of clay slates, fine-grained sandstones and grits, calcareous mudstones and limestones. The veins, about 64 of which are known, are mainly under 4 feet in width, productive in both granite and sedimentary rocks, and composed of quartz with cassiterite, wolfram, scheelite, tourmaline, pyrite, arsenopyrite, and a little chalcopyrite and galena. Outcropping on a steep mountainside they have been developed by adits at varying elevations. A self-acting ropeway, over a mile long, connects the mine with the mill 1,339 feet below, and with a capacity of 160,000 tons of ore per annum. A road, some 80 miles in length, constructed by Mawchi Mines Ltd, connects with the Burma Railways at Toungoo. The ore reserves at the end of 1938 were 712,540 tons carrying 3.02 per cent mixed concentrates which in that year assayed 38.39 per cent tin and 32.20 per cent wolfram. The total recorded output between 1904 and 1939, inclusive, was 24,991 tons of tin concentrates. Prospecting licenses were held over three more areas in Karenni. The post-war development of this exceptionally good mineral deposit has been prevented by armed conflict between the Burmese and Karen peoples. When these cease, granted the benefits of a sympathetic administration, the future of Mawchi is assured, and it will make once more its large and valuable contribution to the tin and tungsten mining industries of Burma for many years to come.

Production figures of Burmese tin ore commence in the period 1898-1903, with an average annual output of 82 tons, and the next period, 1904-8, registered little change with 83 tons yearly. This rose to an annual average of 124 tons over the quinquennium 1909-13, and thereafter the growth of the industry is apparent from the figures in the following table and from the graph on page 172.

No reliable statistics of production are available for the post-war period until 1947, when 1,270 tons of tin concentrates and 1,220 tons of mixed tin and wolfram concentrates were produced. The corresponding figures for 1948 and 1949, which we owe to the courtesy of Dr Ba Thi of the Burma Geological Department, were as follows:—Tin Concentrates 1,768 and 1,188 tons: Mixed Concentrates 2,122 and 1,469 tons. In 1950 and 1951 the output of tin ore was 1,816 and 1,295 tons and of mixed tin and wolfram concentrates 901 and 1,207 tons, for the respective years. The disturbed conditions in the tin mining areas since Burma became an

TONS

9000

8500

8000

7500

7000

6500

6000

5500

5000

4500

4000

3500

3000

2500

2000

1500

1000

500

0

1900

1905

1910

1915

1920

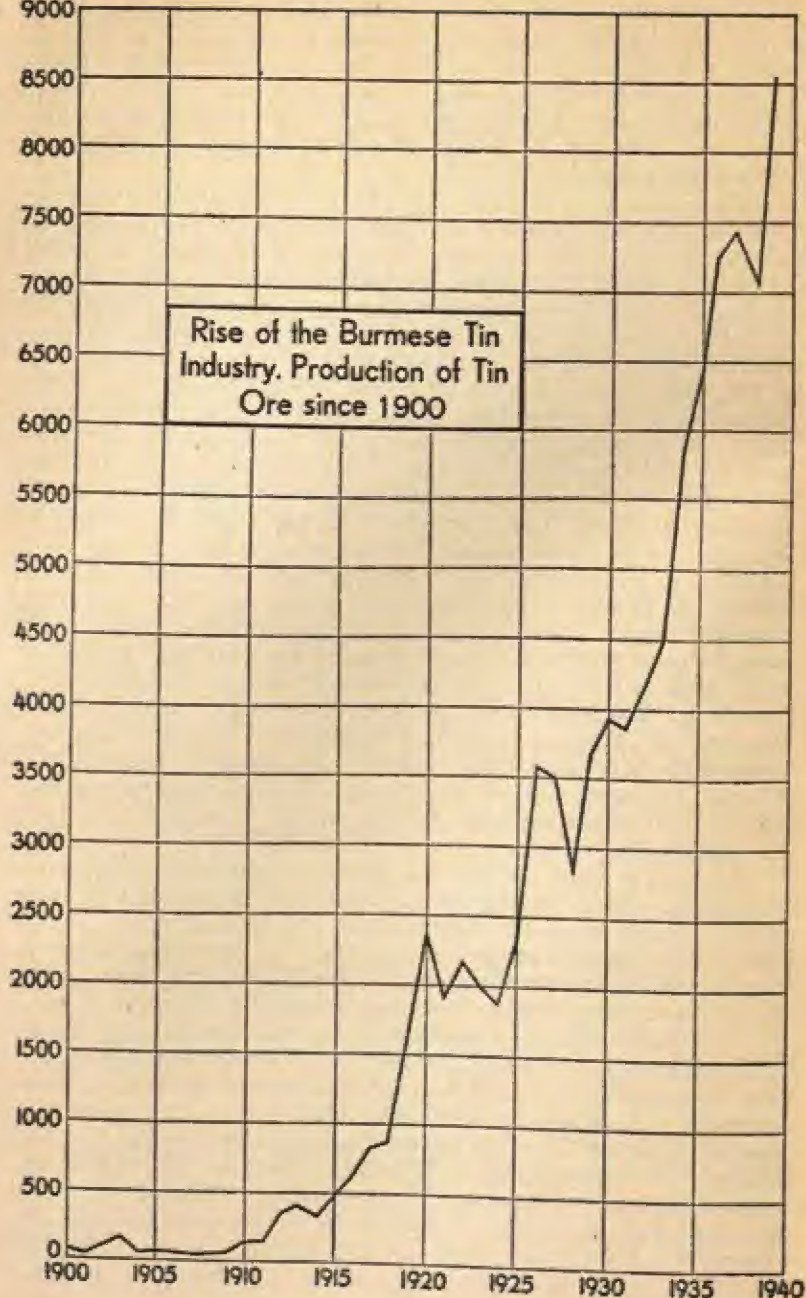
1925

1930

1935

1940

Rise of the Burmese Tin
Industry. Production of Tin
Ore since 1900



AVERAGE ANNUAL OUTPUT OF TIN CONCENTRATES IN BURMA,
1914-39

YEAR	CONCENTRATES TONS	TIN METAL IN CONCENTRATES TONS (estimated)
1914-18	650	455
1919-23	2,051	1,436
1924-8	2,817	1,972
1929-33	4,040	2,828
1934-8	6,824	4,777
1939	8,520	5,964

independent republic in 1948 have hindered the rehabilitation of the industry and as late as September 1951 it was reported that mining was at a standstill in some districts.

Between 1914 and 1939, the average annual value of the tin concentrates produced in Burma rose from approximately Rs 7 lakhs to over Rs 99 lakhs. During the same period, 1914-39, the average annual market price of metallic tin ranged between £118 (in 1931) and £329 per ton (in 1918). In 1939 it was £226 per ton. Ten years later, 1949 closed with the price of tin around £600 per ton, and by the end of 1950 this had risen to £1,290 per ton, as stockpile buying developed in the metal markets and shortages increased due to large-scale purchases by Governments and private consumers in excess of their normal requirements.

In the early years of the present century India's imports of unwrought tin in the form of blocks, ingots, bars and slabs, averaged about 1,500 tons per annum. The changes since then up to 1943 are shown in the table, and later figures are of little use as guides to normal times, owing to disturbances caused to the trade by the war and its aftermath.

AVERAGE ANNUAL IMPORTS AND CONSUMPTION OF METALLIC
TIN IN INDIA, 1924-43

PERIOD	IMPORTS TONS	VALUE RS	CONSUMPTION TONS
1924-8 ..	2,716	95,35,073	2,573
1929-33 ..	2,450	56,01,000	2,410
1934-8 ..	2,429	70,18,672	2,342
1939-43 ..	2,440	78,07,868	2,366

Ninety-seven per cent of this imported metal came from the smelters in the Straits Settlements.

Amongst the alloys of tin imported into India from abroad are the solders, used in a great many industries for joining metallic

surfaces, and the anti-friction and bearing alloys, employed widely in all kinds of machinery. For the five years ending 1937-8 the average annual imports of solder amounted to 258 tons, valued at Rs 4,55,528, while those of the anti-friction metals for the same period were 153 tons, valued at Rs 2,47,289. The Panel Committee was of the opinion that about 4,000 tons of tin in all its forms would be consumed in India during the first five post-war years. The only tin produced in India at present is secondary metal, recovered in small quantities, together with the oxide, from tin-plate scrap in the detinning plant of Messrs Montana Ltd, Bombay, which commenced operations in 1942. In this connexion it is as well to point out that the familiar 'tins', in which food-stuffs of all kinds, tobacco, paints, petrol, paraffin and so forth, are packed, are mild steel containers, coated with a thin layer of tin to preserve them from rust, and that only about $1\frac{1}{2}$ per cent of the weight of an empty 'tin can' is made of metallic tin.

Of an average annual world production, during the five years 1934-8, of 161,119 tons of tin, calculated in terms of the metal contained in the concentrated ore, Malaya with 33.5 per cent, Indonesia with 16.8, Thailand with 7.8 and Burma with 2.9 per cent, were together responsible for 61 per cent of the total. In addition to these countries, Bolivia added a further 15.1 per cent, China 6.5, Nigeria 4.9, the Belgian Congo 3.4 and Australia 2.0 per cent, with a number of other countries contributing smaller quantities still.

With the exception of Bolivia and China (in part), probably over 70 per cent of the world's tin production was won from alluvial and detrital deposits. As regards Burma, where much tin ore is a by-product of wolfram mining, approximately 44 per cent of the 1939 output came from true alluvial deposits, and of this 61 per cent was obtained by dredging and the remainder by gravel pumping and ground sluicing.

The established tin fields of the world are today more than capable of meeting normal peace-time demands, indeed, before the second world war, international schemes of voluntary output restriction were applied to maintain a profitable price for the ore. In support of this policy the Government of Burma stopped the issue of prospecting licenses for tin ore for a period commencing in 1935. The later effects of the Japanese invasion and of the unsettled conditions following it are too apparent to need comment. Under all these circumstances it is not surprising that Burmese tin mining shows so little progress. The Government of Burma has suggested that the tin companies operating in Lower Burma should combine and enter into a joint venture with the Government, but by the end of 1953 only exploratory discussions of the proposal had taken place.

A time is approaching, however, when the easily worked surface and sub-surface deposits of Indonesia and Malaya (where no less

than 76 dredges, 518 gravel pumps and 23 hydraulic plants were operating in 1949), will show signs of inevitable exhaustion. It is then that Mergui and other parts of Burma will receive attention commensurate with the great extent of their tin-bearing rocks and their weathered products. In the meantime, as the late E. L. G. Clegg wrote in 1940, 'the fundamental necessity of the tin (and wolfram) areas in Burma is undoubtedly the improvement of their roads and tracks'.

CHAPTER IV

FERROUS AND OTHER RELATED METALS

IRON

THE approximate time of the commencement of iron manufacture in India is unknown, but at the time of Alexander's invasion (326 B.C.), the armed nations of northern India were as familiar with iron and steel as the Greeks themselves. The famous pillar at the Kutb, near Delhi, is of solid wrought iron of an excellent type, 23 feet 8 inches in length, 16½ inches in diameter at the base and 12 inches below the capital. It weighs over 6 tons and bears the epitaph, in Sanskrit, of King Chandragupta II, composed in or about A.D. 415. The manufacture of *wootz*, an Indian steel, anticipated the principle of the cementation process by many centuries, and this material was probably exported to western lands from before the Christian era, to be worked into the 'Damascus' swords of medieval times. Until it practically succumbed, in comparatively recent years, before the competition of imported metal, the indigenous iron industry was both widespread and prosperous and there is hardly a single district from the extreme south of India to the Himalayas, or from the Shan States in the east of Burma to Baluchistan in the west of Pakistan, with the exception of the alluvial plains of the great rivers, in which ancient iron slags have not been found. It does not follow, however, that ores suitable either in quantity or quality for the needs of a modern blast furnace plant exist in all these places.

Failure attended every early attempt to graft European methods on to the local processes and to smelt iron ores on a large scale in India. In 1830, the Indian Steel, Iron & Chrome Co. was established by J. M. Heath with its works at Porto Novo in South Arcot district, Madras, where ores from the Salem district were smelted. These works were subsequently carried on by the Porto Novo Steel & Iron Co. and the East Indian Iron Co., additional furnaces being erected at Tiruvannamalai in North Arcot, at Beypur in Malabar in 1833, and at Palampatti in the Salem district in 1853. Pig iron from the Porto Novo works was shipped to steel-makers in Sheffield, and a large quantity of it was used in the construction of the Britannia tubular and Menai bridges in the United Kingdom. These concerns never paid a dividend, steadily lost their funds and finally closed down about 1867.

In Bengal the story begins with the grant by the East India Company to Messrs Farquhar & Motte, in 1778, of an exclusive

right to manufacture iron within the Company's territories, a privilege which they enjoyed in the Birbhum district, in all probability using local methods, until they relinquished their grant in 1795. In 1839 Messrs Jessop & Co. conducted inconclusive experiments with Burdwan ore. In 1855, Messrs Mackay & Co. started on a small scale at Mahomed Bazaar, also in the Birbhum district, and their desultory operations were abandoned in 1875 after final experiments by Messrs Burn & Co. had proved them unprofitable. In the meantime the Kumaun Iron Works Co. Ltd had been formed in 1862, amalgamating plants which had been erected at Dechauri and at Khurpa Tal, in the Naini Tal district of Uttar Pradesh, in 1857. After many vicissitudes this enterprise failed as the others had done. Yet another attempt made in 1862, at Barwai in Indore, under the direction of a Swedish metallurgist, met with no better success. In all these undertakings charcoal was the fuel used, or proposed, and it was not until 1875 that advantage was taken of coke made from Indian coal. In that year a private company built two furnaces at Kulti, near Barakar, on the Raniganj coalfield, each capable of producing 20 tons of pig iron per day, but owing to insufficiency of capital it ceased operations in 1879, after making 12,700 tons of pig iron. In 1882 this plant was taken over by the Government and one furnace was restarted in 1884, continuing until 1889 when the works were resold to the Bengal Iron & Steel Co. Ltd, the predecessors of the Bengal Iron Co. Ltd, registered in 1919. The plant was entirely remodelled and the Company soon established iron smelting in India on permanent foundations, though a steel plant added in 1903 was shut down in 1905. Later developments include the formation of the Tata Iron & Steel Co. Ltd, the two original furnaces of which were 'blown in' in 1911 and 1912, at Jamshedpur, 154 miles west of Calcutta; the inauguration of the Indian Iron & Steel Co.'s furnaces at Burnpore, near Asansol, on the Raniganj coalfield in 1922; the completion of the Mysore Government's charcoal iron scheme at Bhadravati, near Shimoga, in 1933; and the amalgamation of the Bengal Iron Co. Ltd with the Indian Iron and Steel Co. Ltd, with works at Kulti and Hirapur, near Asansol, in 1936.

IRON ORE DEPOSITS OF BIHAR AND ORISSA

At the beginning of the present century the annual production of iron ore in India averaged about 65,000 tons; by the period 1939 to 1943 this average had risen to more than 3,000,000 tons per annum. The total amount of iron ore raised in India up to the end of 1950 was 70,658,400 tons, and of this amount no less than 67,778,000 tons, or 96 per cent, came from the mines of Bihar and Orissa; indeed, in recent years, more than 98 per cent of the ore supply has been drawn from these two States alone. The distribution of this and the remaining tonnage over the past 50 years is

shown in 5-yearly periods in the table on p. 192. As far as the Bihar and Orissa output is concerned, Singhbhum, in Bihar, where mining started in 1904, has contributed 47 per cent to the total; Mayurbhanj, in Orissa, which began to produce in 1911, 42 per cent, and Keonjhar, also in Orissa, the latest comer to the list, in 1927, 11 per cent approximately.

One of the pioneer geologists of Bengal, Pramatha Nath Bose (1855-1934), the first Indian to be appointed to the graded staff of the Geological Survey of India, discovered the haematite deposits of Gurumaishini and other places in Mayurbhanj in 1904, while R. Saubolle, a prospector of Martin & Co., Calcutta, found those of Pansira Buru and Buda Buru, in Singhbhum, in 1907, for the ores that had been worked earlier in that region were the magnetites of the ultrabasic magnesian rocks in the neighbourhood of Kalimati near Tatanagar railway station. Later work by various geologists revealed that in a region lying from 150 to 200 miles west of Calcutta, within parts of Singhbhum, Keonjhar, Bonai and Mayurbhanj, there exists one of the major iron ore fields of the world in which enormous tonnages of rich ore are readily available. It occurs usually at or near the tops of hill ranges, the most important of which runs from near Rontha in Bonai in a north-north-easterly direction, rising 1,500 feet above the surrounding plains, for about 30 miles: along practically the whole of this length, with a few negligible breaks, high-grade haematite, averaging over 60 per cent of iron, is found. Smaller ranges roughly parallel to the main one also contain good ore. In 1934, H. C. Jones estimated the minimum quantity of ore with not less than 60 per cent iron, then known, at 2,701,000,000 tons, distributed as follows in the various areas—Singhbhum 1,047, Bonai (now in Sundargarh district) 648, Keonjhar 988 and Mayurbhanj 18 millions of tons.

In the Hirapur hills, some 5 or 6 miles west of Umarkot, in the Koraput district of Orissa, there is a minimum quantity of 10 million tons of haematite averaging perhaps 60 per cent of iron and 0.3 per cent phosphoric oxide (P_2O_5), and ranging up to 62.7 per cent iron, according to A. M. N. Ghosh. In 1939-40 B. C. Roy examined the widely scattered lateritic deposits of Sambalpur, ten of which he concluded contained 50 million tons of ore with 55 to 60 per cent of iron and 0.31 per cent of phosphorus; the largest of these, on the Nalibassa hill, has about 15 million tons of ore. A large deposit of haematite was discovered recently on the Tomaka Range in the Sukinda area of the Cuttack district, Orissa, by G. P. Rath. A representative sample of the surface ore contained 68.7 per cent iron, 0.016 per cent phosphorus and under 0.01 per cent sulphur. The total reserves are said to be of the order of 27 million tons of various grades. The deposit is now being worked for export.

Further investigation by Dr M. S. Krishnan soon increased the Keonjhar reserves to 1,483,250,000 tons. Later revaluations here and

elsewhere, as a result of further geological surveys and the evidence brought to light as mining operations have extended, enable the Geological Survey of India today to compute the probable total amount of high-grade iron ore available in Bihar and Orissa as approximately 8,000,000,000 tons, most of which can be won by open-cast methods. Moreover, there is perhaps double that quantity of lower-grade workable ore, to say nothing of vast tonnages of banded haematite, quartzite and ferruginous laterites containing around 30 per cent of iron. Mining operations have also shown that the solid haematite gives place to an unconsolidated or powdery variety at different depths.

The Iron Ore Series consists of conglomerates, purple sandstones and limestones, overlain by ferruginous shales and banded haematite quartzites with the iron orebodies, followed in their turn by another thick, shaly group with epidiorites and ash beds. The whole Series is of Archaean age and forms the uppermost of the two unconformable groups into which the Dharwarian rocks of Singhbhum have been divided.

Many theories have been advanced to account for these vast iron ore deposits but the one most generally put forward and accepted by H. C. Jones, F. G. Percival and Dr M. S. Krishnan is that originally their iron contents were marine, chemical precipitates, probably from solutions carried into the sea through the leaching of adjacent land masses. From them in the long course of geological time, the banded haematite quartzites and the haematite jaspers were formed, which many observers consider to be the mother rock of the ores. There is much field evidence tending to prove that the ores themselves arose through the replacement of the silica of the haematite quartzites by hydrated ferric oxide which later became converted into haematite. The removal of the silica and the replacement processes were brought about by the action of descending meteoric waters, and in those locations where the replacement has not been completed, broken, slumped, crumbly, porous, slabby and powdery ores exist.

M. V. Wazalwar¹ and others, however, take another view and believe that the shales are chiefly responsible for the formation of the iron orebodies and for that matter for the manganese ores of Keonjhar and Bonai as well. They hold that the original iron and manganese contents of the shales were unevenly distributed, possibly along certain well-defined zones, stating that the shales themselves have been found to pass laterally into banded magnetite quartzites as well as into banded manganese ore varieties. The quartzite masses in the shales, they think, are of a secondary character and seem to have been formed by percolating solutions in the zone of oxidation. At a later stage, the leaching out of silica and the enrichment of iron, as a result in large degree of colloidal

¹ Personal communication.

reactions, led to the building up of the orebodies. They also adduce evidence of the genesis of oxidic ores through an intermediate hydroxide stage aided locally by the comparatively high temperatures brought about by the intrusion of basic dykes, granites, pegmatites and quartz veins into the shales. The formation of the iron orebodies was on a much grander scale than that of the manganese ore deposits, which tend rather to occur as both large and small, irregular, segregated masses.

Dr J. A. Dunn (1935) divided the Iron Ore Series as follows:

5. Dalma series of volcanic flows.
4. Tuffs, lava flows, shales, phyllites and mica schists, quartzites and conglomerates.
3. Shales, phyllites and mica schists.
2. Limestones.
1. Sandstone conglomerates.

The iron ores and associated banded haematite quartzites occur in Zone 4. Dunn rejected the theory of their sedimentary origin and argued that they were formed by the secondary silicification of material now represented by ferruginous, chloritic or carbon shales or phyllites, many of which were tuffs in the first instance. He thought that this silicification was in part contemporaneous with the deposition of the beds themselves and resulted from thermal activities which accompanied the formation of the volcanic series. The iron, according to Dunn's views, was derived partly from the oxidation of the tuffs and flows *in situ* and partly represents a wash from them. Later solutions are believed to have rearranged the ferruginous contents with the production of the massive iron ores.

The haematites vary much in their physical qualities, and massive, laminated, micaceous, powdery, lateritic and brecciated kinds occur. The iron content is usually about 64 per cent, phosphorus ranges normally from 0.03 to 0.08, but may be as high as 0.15 per cent, sulphur is usually below 0.03 per cent. The chief characteristics of these ores are their high iron, low sulphur and titanium, and variable phosphorus contents.

IRON ORE MINING IN SINGHBHUM AND KEONJHAR

The Indian Iron & Steel Co. Ltd, the successors in title of the Bengal Iron Co. Ltd, has been exploiting since 1938 the deposits of Pansira Buru and Buda Buru in Singhbhum, 12 and 8 miles respectively south-east of Manharpur station on the Eastern Railway, to which they were connected by a light line about 1911. An aerial ropeway, carrying 40 tons per hour, transports the ore from the top of Pansira Buru to the storage bins at its foot, whence it is discharged automatically into the railway wagons. A gravity incline, with a capacity of 60 tons per hour, brings ore down from a spur of Buda Buru to the railway at its foot. The total quantity of ore available at Pansira Buru was originally estimated at nearly

10 million tons and at Buda Buru at 150 million tons. In both localities it is a high-grade haematite with the following average composition:

Iron	..	64.0 per cent	Magnesia	..	0.18 per cent
Silica	..	2.10 " "	Manganese oxide.	0.05 " "	
Lime	..	0.15 " "	Sulphur	..	0.002 " "
Alumina	..	1.25 " "	Phosphorus	..	0.05 " "

The Gua mines of the same concern are also in Singhbhum, near the termination of a branch line of the Eastern Railway, ore dispatches having commenced with its completion in 1923. At present about 2,500 tons of ore are moved daily, by three self-acting inclines, to the head of a ropeway which delivers it to the railway.

The ores of the Bagia Buru range, which runs parallel to the Bara Jamda-Barabil branch of the Eastern Railway, have been quarried by the United Steel Corporation of Asia Ltd, a company managed by Messrs Bird & Co. Ltd, since 1923. These workings are in Keonjhar and yield haematite containing 58 to 60 per cent of iron. This concern, having at present no plant of its own, sells its ore to other smelters and at one time exported a substantial tonnage outside India. Manganiferous iron ores, containing between 30 and 35 per cent of manganese and about 20 per cent of iron in the form of limonite, are also obtained in the same vicinity and are sold to iron manufacturers in India.

The Noamundi mine of the Tata Iron & Steel Co. Ltd is also in Singhbhum, though its orebodies actually extend into Keonjhar. It is connected to the Amda-Gua extension of the Eastern Railway, to which two aerial ropeways deliver ore to the bins at Noamundi station. Discovered by R. Saubolle and C. R. N. Aiyengar, independently, in 1917, it consists chiefly of two parallel ridges, each about $2\frac{1}{2}$ miles long and $\frac{1}{2}$ mile wide at the north, becoming much broader at the south, and was described in detail by F. G. Percival (1931). He classified its ores into two grades, the first of which includes the massive and laminated haematites as well as the lateritic ones, while the second embraces the powdery and soft, shaly ores. The reserves of the former were estimated at 140 million tons and of the latter at 88 million tons. Dispatches commenced in 1926, while the bulk of the ore handled today is of the laminated type and averages about 60 per cent iron, 4 per cent silica and 5 per cent alumina. The soft powdery ores, both here and elsewhere, are of no immediate interest, for though they are rich in iron and could be sintered economically, they are not likely to be used while supplies of hard ore are so readily available for the blast furnaces.

Singhbhum and Keonjhar together supplied over 57 per cent of all the iron ore smelted in India up to the end of 1946, the former exceeding an annual output of one million tons in 1927 and, with varying fluctuations, reaching a peak of 1,800,574 tons in 1941,

falling again to 974,805 tons in 1946, and averaging 1,406,823 tons yearly over the decade 1937 to 1946. Keonjhar passed the half million ton mark with 507,133 tons in 1944 and its average for the same decade was 401,531 tons per annum.

IRON ORE MINING IN MAYURBHANJ

Over twelve deposits of high-grade iron ore occur in the more accessible parts of Mayurbhanj, and three of them—Gorumahisani, Sulaipat (Okampad) and Badampahar—have been developed by the Tata Company. They are all joined to the Eastern Railway by a branch line about 56 miles in length. The ores are of the same types as those of Singhbhum and interbedded with them are haematite quartzites and shales. Gorumahisani is a hill mass with three separate peaks, the highest of which rises 3,000 feet above sea level. Estimated to contain 9,800,000 tons of ore by E. Curnow in 1914-15, it has actually yielded over 13 million tons, while later discoveries of rich material both *in situ* and as detritus have so augmented the reserves that at the end of 1946 they still amounted to some 19 million tons. An average of 20 analyses of detrital ore shows iron 61.46, phosphorus 0.048, sulphur 0.036, silica 3.34 per cent. The average composition of ten samples of solid ore shows iron 64.33, phosphorus 0.075, sulphur 0.021 and silica 1.64 per cent.

Okampad and Sulaipat (2,535 feet) are prominent peaks, a mile apart and some 12 miles south-south-west of Gorumahisani. The railway reached the neighbourhood in 1922 and a tram line connects the mine with it. The main orebody, again associated with banded haematite quartzites, lies at the crest of the hill and, with an outlier, was estimated by Curnow to contain 2,270,000 tons. On the removal of the rich 'float' ore, however, further ore bands were discovered, so that although approximately 3,186,000 tons had been removed, the remaining reserves at the end of 1946 amounted to 850,000 tons. The Sulaipat ore is low in phosphorus and one of the finest in quality.

The Badampahar deposit occupies the 2,706-foot peak of the same name in the Sulaipat-Badampahar range, $8\frac{1}{2}$ miles south-west of the Sulaipat mine. Its reserves, according to Jones, were about 7 million tons in 1928, but in 1940 further discoveries of large orebodies greatly increased them, so that by 1944 they were still of the order of 44 million tons. Dispatches up to December 1946 totalled 7,416,000 tons. A yellow ore, long neglected because of its poor appearance, is now mined; its bulk analysis shows iron 66.6, silica 0.72, alumina 0.42, phosphorus 0.062, sulphur 0.15, combined water 2.40 per cent and, like many of these ores, no titanium. The yellow colour may be due to the presence of 'limonite' and the ore seems to be a product of replacement of a basic igneous rock. A small, isolated mass of magnetite also

exists, but the greater bulk of the Badampahar ore is haematite which, while not so high in iron content as the varieties from Gorumahisani or Sulaipat, is highly valued by the smelters on account of its more porous character. A representative sample, quoted by Jones, had a composition of iron 57.60, manganese 0.52, silica 5.60, alumina 5.02, phosphorus 0.074 per cent; the average composition of the ore as mined in 1945-6 was iron 55.60, silica 7.39 and alumina 2.88 per cent. Work was commenced at both the Sulaipat and Badampahar mines in 1922.

The output of iron ore from Mayurbhanj, responsible for over 42.5 per cent of the total won from Bihar and Orissa up to the end of 1946, approached closely to 1 million tons per annum by 1924 and passed that figure by 1926. It then declined on the whole over a series of years, only to rise again later, so that the annual average for the decade ending 1946 reached 950,615 tons.

SMALLER DEPOSITS OF THE ORES OF IRON

The enormous ore deposits of southern Singhbhum completely overshadow smaller ones of a similar character in various parts of Chota Nagpur which cannot be mined in competition with them. Others of different characters, both here and elsewhere, may find their special uses, as was indeed the case with the magnetites of Kudada and Patharghara, now exhausted, but worked at one time for the manufacture of high-phosphorus foundry pig iron. Similar magnetite ores occur on Gore Pahar, in Palamau, where Auden has estimated reserves of about 350,000 tons; at Sua, near Daltonganj, where A. K. Dey discovered another deposit, and near Sankhamur in Pallahara, Orissa, where B. C. Gupta found lenses of manganiferous magnetite. Analyses of the Gore Pahar ore show ferric oxide 69.23 to 72.66, ferrous oxide 21.60 to 22.50, silica 1.40 to 5.54, titania 0.50 to 1.60, alumina 0.50 to 1.10 and phosphorus pentoxide 0.02 to 0.03 per cent. The titanium- and vanadium-bearing iron ores are described separately under TITANIUM and VANADIUM and it remains to mention the lenticles and nodules of a softer, limonitic, clay-ironstone character found in the Damuda Valley coalfields which served as a source of iron in the early days, and for which demand may arise again, for their use, after suitable treatment, in the desulphurizing processes of coking plants and gas-works.

IRON ORE DEPOSITS OF MADHYA PRADESH

The iron ores of Madhya Pradesh are not systematically worked at present, though they have been drawn upon, as, for example, in 1923 and 1924, when for various accidental reasons, the mines of the companies operating in Singhbhum were unable to furnish regular supplies for their furnaces.

In the Chanda district at least ten separate deposits have been located, forming well-developed beds of haematite, sometimes with magnetite, associated with banded haematite quartzites of Dharwarian age. The two best known are at Lohara, described by Hughes in 1873 and by P. N. Dutta in 1910, and Pipalgaon (Hughes 1873). The former crops out in a hill nearly half a mile long, 200 yards wide and 120 feet high, and has been traced for a further $2\frac{1}{2}$ miles. Regarding it Hughes wrote as follows: 'The view presented by such a mass of almost pure specular iron it does not fall to the lot of many men to see surpassed and those who possess the opportunity of visiting this place ought to do so, and carry away with them the remembrance of having looked upon one of the marvels of the Indian mineral world.' The Pipalgaon deposit he described as: 'An excessively fine mass of red haematite resembling that which occurs at Lohara if not having the same composition.'

The available quantities and compositions of the ores of these two, and of two further localities, Asola and Dewalgaon, as proved by V. R. R. Khedker in 1946, are shown in the following table:

ANALYSES OF GHANDA IRON ORES

	Reserves tons	COMPOSITION							
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	FeO	P	S	TiO ₂	Total Fe
Lohara ..	21 million	1.44	1.52	91.36	5.38	0.02	0.12	nil	99.84
Pipalgaon ..	300,000	1.56	1.07	82.37	14.12	0.09	0.10	nil	99.90
Asola ..	400,000	8.26	2.48	81.22	7.90	0.08	0.11	nil	100.00
Dewalgaon ..	250,000	2.90	2.24	85.35	9.33	0.02	0.14	nil	99.90

The ores of the Drug district were briefly described by Bose in 1887 and he noted that the most extensive deposits occurred in the Dhalli-Lohara *zemindari*. This region was investigated by C. M. Weld for the Tata Company in 1914. The iron ores resist the action of denudation and rise in hillocks above the level of the surrounding country. The ridge which includes the Dhalli and Rajhara hills extends for about 20 miles and attains heights of 400 feet above the plains. The ores are associated with phyllites and are often of the quartz-iron ore schist type, while the purer varieties form lenticular bodies at two horizons; those in the lower band being from 2,000 to 3,000 feet in length and 100 feet or so in thickness but the others in the upper band are comparatively smaller. The limited mass of haematite forming the crest of Rajhara Hill itself was proved by core-boring to contain $7\frac{1}{2}$ million tons of ore with about 67.5 per cent of iron and a phosphorus content just below the Bessemer limit. More recent work has demonstrated that this is just a small portion of the reserves available here, for the western portion of Rajhara Hill is now known to contain a

further 37½ million tons, while additional amounts of 24, 25 and 20 million tons are believed to be available near Jharandalli, Kondekasa and to the south-east of the latter place, respectively. The composition of the Rajhara ores is shown by the following analyses, the average of 64 samples :

ANALYSES OF RAJHARA IRON ORES

		IRON	PHOS- PHORUS	SULPHUR	SILICA	MANGANESE
Surface ore	..	66.35	0.058	0.108	1.44	0.151
Core ore	..	68.56	0.064	0.071	0.71	0.175

It has long been known that extensions of these ore deposits were to be found in Kanker and Bastar, to the south of Drug, and to P. N. Bose again goes the credit of noting two extensive deposits in the Antagarh *tahsil* of Bastar, over 50 years ago. It is only within recent years, however, that their magnitude and quality have been realized. H. Crookshank reported in 1938 that there are cliffs of iron ore, up to 500 feet in height, in the Bailadila Range of Bastar, capable of yielding at least 610 million tons of first-class ore with over 68 per cent iron, 0.096 per cent phosphorus and 0.042 per cent sulphur. Later work by A. M. Heron and D. K. Chatterjee increased these reserves to 3,600 million tons. Again, on the crest of the Rowghat, there are, according to D. K. Chatterjee, 740 million tons of haematite, with some limonite, within a depth of 150 feet of the surface. An average analysis of 34 samples from this area gave iron 64, phosphorus 0.08, and silica 1.76 per cent. The largest individual deposit on the south-west of the ridge contains some 500 million tons, the average of ten analyses of which showed iron 65.86, phosphorus 0.05, and silica 1.04 per cent. In some of these deposits the ores are soft and porous and, at times, limonitic.

In Kanker, Bastar district, K. K. Dutta and P. K. Chatterjee have found about 6 million tons of massive haematite with over 64 per cent of iron and practically no phosphorus, on the Ari *dungri*, near Parrekoro. A further 20 million tons of detrital, micaceous and specular haematite, in plates and slabs up to 4 feet across, is available, within a depth of 5 feet, around the base of the Ari *dungri*.

IRON ORES OF MYSORE

The ores of iron are widely distributed in Mysore but the only ones under exploitation are those of the Bababudan Hills, in the Chikmagalur district, originally described by Smeeth and Iyengar, as well as certain others including Sandur, Hospet and Ramagiri,

which accrued to the State after its merger with the Bellary district in 1953. The crest of the Bababudan horseshoe-shaped chain of hills is formed almost entirely of banded quartz-iron ore rocks, largely haematite with some magnetite. The ores themselves, according to Smeeth, are either desilicified portions of these rocks or metasomatic replacements of quartz and silicates resulting in the formation of rich haematitic and limonitic mixtures, particularly on the more gentle slopes and undulations. Sampat Iyengar regarded the more or less banded and porous limonite-haematite ores as depositions of iron compounds removed in solution by meteoric waters from portions of the desilicified ferruginous quartzites. No estimates appear to have been made of the total ore reserves of these fields, though Smeeth gives figures for certain independent occurrences which are now superseded by the recent investigations of J. P. David. In the ridge and scarp of the Dupadagiri section of the Kemmangandi field he has proved the presence of 20 million tons of ore, averaging 54 per cent iron, 7 per cent alumina, 3 per cent silica and 0.10 per cent phosphorus, after making an allowance of 50 per cent in the total for rejections on account of lateritic impurities. The ores of the Kalhattigiri section are, according to David, of inferior quality to those of Kemmangandi, and the reserves of workable ore therein are unlikely to exceed 10 million tons. Formerly, only ores averaging about 60 per cent iron were won for the Mysore Iron Works at Bhadravati, but today material ranging between 55 per cent and 60 per cent iron is supplied to them.

At Kemmangandi the ore is transported from the ridge to the base of the hill by a mono-cable ropeway, erected in 1924, and thence by tramway to the Bhadravati works, 23 miles away. A bi-cable ropeway, three miles long, is under construction, the upper terminus of which, 3,000 feet above its lower end, is in tramway connexion with the scarp and Dupadagiri sections. Mining commenced in 1923, and up to the end of 1946 787,256 tons of ore had been removed. Output varies with the demand for charcoal iron, and over the decade 1937 to 1946 averaged 37,157 tons per annum.

In Sandur, rich haematites derived from haematite quartzites are found as cappings, 100 to 200 feet thick, in association with manganese ores. These have been investigated by M. S. Venkatram who estimates that they contain a total of about 130 million tons, within 50 to 80 feet of the surface, in the following areas:

Donimalai ..	25,600,000 tons	Kanavehalli Range.	500,000 tons
Devadari Range ..	15,000,000 "	Ramandrug ..	30,300,000 "
Kumaraswami-		Timmappanagudi.	32,800,000 "
Kammadheruvu.	25,400,000 "		

In the extension of the Sandur ranges into Hospet taluk, there are, according to M. Krishna Murthy, about 6 million tons of haematite with iron content ranging between 60 and 65 per cent. The ores

vary from soft to hard, massive, steel grey types and usually contain over 60 per cent of iron. About 2 million tons of iron ore of much the same quality are available in the Copper Mountain to the south-west of Bellary.

No account of the iron ores of Mysore would be complete without a brief reference to the discontinuous bands of ferruginous quartzites, and the magnetite-quartz rocks derived from them, which stretch from the south-western corner of the Bangalore district, across Tumkur into the Chitaldrug district. The magnetite-quartz rocks of the Maddur-Malavalli area of Mandya are amenable to magnetic concentration and yield products averaging 60 to 70 per cent of iron, with no more than traces of phosphorus, sulphur and titanium. B. P. Radhakrishna has estimated reserves of these rocks amounting to $41\frac{1}{2}$ million tons, carrying an iron content of between 40 and 50 per cent. Similar ores, amounting to some 13 million tons, are said to be available in the Sargur area. In the Kunigal area of Tumkur there are probably a further 32 million tons to be found, but as garnet, hypersthene and amphibole are also present, they may prove of inferior quality. The Hiriyr area of Chitaldrug, Radhakrishna has computed, contains 55 million tons of brown haematite assaying 80 per cent of ferric oxide, with traces of sulphur and phosphorus, but a certain proportion of this consists of soft, powdery ore. In the Shimoga district too, which lies to the west of Chitaldrug, limonitic ores associated with manganese ores occur on the crest of Shankarguda. Analyses of these ores range up to 60 per cent of iron, but their high phosphorus content (0.1 per cent) precludes their utilization at present.

IRON ORES OF MADRAS & ANDHRA

Iron ores are abundant enough in the Salem district of Madras to have led so astute a geologist as the late Sir Thomas Holland to declare that they are practically inexhaustible. For full details of their many occurrences in this and other districts of the State, the reader must be referred to the publications of the Geological Survey of India, and particularly to the writings of W. King and R. Bruce Foote, as only a selection from the recent investigations can be mentioned briefly here.

N. K. N. Aiyengar examined a large number of magnetite-bearing quartzite bands in the Salem-Tiruchirapalli (Trichinopoly) region in 1947 and found them intercalated with mica and chlorite schists, garnetiferous amphibolites and gneisses of Dharwar age. He regards the magnetite as a metamorphic derivative of haematite which, with an amphibole of the iron-bearing grunerite group, occurs in these ores in small quantities. Holland had already suggested that the common occurrence of magnetite with the haematite represented a stage in the thermal metamorphism of haematitic quartzites. The reserves of the more conspicuous and

richer bands are conservatively estimated at 305 million tons, with an iron content of 35 to 40 per cent and phosphorus 0.03 to 0.15 per cent, distributed as follows:

Kanjamalai ..	55,000,000 tons	Attur area ..	12,000,000 tons
Godumalai ..	12,500,000 "	Tirthamalai ..	48,000,000 "
Perumamalai ..	10,000,000 "	Rasipur-Namakal.	34,000,000 "
Chitteri and		Kollaimalai ..	67,000,000 "
Tainanda Hills ..	55,000,000 "	Pachchaimalai ..	11,000,000 "

A comprehensive report on these iron ores by Dr M. S. Krishnan and N. K. N. Aiyengar has been published by the Government of Madras. The magnetite at the foot of the Kanjamalai near Virapandi station in Salem is said to exhibit polarity.

In the Nidle, Konaje and Yenakal reserved forests and in the hills east of Kirmadka and Ajana of the Puttur taluk of South Kanara, S. Krishnaswamy and B. R. C. Iyengar have found ferruginous quartzites locally giving rise to lateritic iron ores containing over 50 per cent of iron. Lying near the coast these deposits are favourably situated for export purposes, but their extent, depth and reserves still need determination.

Several occurrences of good haematite, partly specular in character, have been developed along a fault plane which cuts across the basal Cuddapah rocks, and trends in an east to west direction, through Veldurti and Ramallakota in the Kurnool district, Andhra. These deposits were the subject of a detailed report by Dr M. S. Krishnan and M. S. Balasundaram, published by the Government of Madras, and contain some 4 million tons of ore within a depth of 100 feet from the surface, with an iron content ranging between 48 and 65 per cent and sulphur and phosphorus between 0.008 and 0.01 per cent, respectively. As far as existing knowledge goes the only other deposits in Andhra worthy of mention are those of the Copper Mountain in the Rayadrug taluk of Anantapur district where, according to M. Krishna Murthy, haematite of the order of 500,000 tons with over 60 per cent iron is available and the occurrences of Chabali, Pagadalapalle and Rajampet in Cuddapah, assumed to be capable of yielding some 300,000 tons, of which about one quarter may carry an iron content of 60 per cent or more. In the Chittoor district there is a band of iron ore, with up to 48 per cent of iron, near Sirsanambedu, which extends in a south-westerly direction into Nellore district. Detrital ore lying within three feet of the surface is being worked at present north of Jaggayyapeta in Krishna district and in the adjacent parts of Hyderabad, but the total reserves may not exceed 1½ million tons with 60 per cent or more iron content and up to 0.05 per cent phosphorus. Veins of magnetite in acid charnockites reported from near Bhimavaram, Yelleswaram, etc., in the Agency Tracts of the East Godavari district are apparently too small in extent to be of value.

IRON ORES OF HYDERABAD

The iron ores of Hyderabad occur in bands made up of crumpled, alternating layers of haematite (or magnetite) and quartz, $\frac{1}{8}$ to $\frac{1}{4}$ inch thick, the two minerals being present in approximately equal amounts. They are, in fact, typical banded haematite quartzites of Dharwarian age with an average iron content of about 40 per cent. As a general rule the bands run in straight lines and may be up to 3 or 4 miles long; their average thickness is about 50 feet, and their maximum thickness in the Chityal hills of the Adilabad district is 160 feet. They generally possess high dips and are often vertical, though in the Amberpet hills of the Karimnagar district, an exceptionally low dip of 22° upwards has been measured. Massive unlaminate iron ore without quartz is rare in Hyderabad; for example, in the whole of the Godavari river section at Chityal, with its total of 160 feet of ironstones, only one layer of solid ore up to 6 inches in thickness is known and it is only traceable for a few yards. Six main deposits have been mapped, each of which contains over five million tons of ore down to plains' level: Chityal, Kalleda-Dasturabad and Rebanpalli in Adilabad; Chandoli (Amberpet) in Karimnagar; Singareni in Warangal, and Kushtagi in Raichur district. There are innumerable smaller orebodies, according to Dr A. M. Heron, from whose account this note is summarized. These iron ores belong to a group common enough in many other parts of India, from which only low-grade, siliceous ores are obtainable without some form of mechanical concentration, and it is obvious that they compare unfavourably with the rich, high-grade ores now used by Indian iron smelters.

No account of the iron ores of Hyderabad would be complete without a reference to Konasamudram (east of Nizamabad), one of the localities where the steel was made from which the Damascus blades of the Middle Ages were fashioned. It was still being made and sold to Persian traders in 1820 when H. W. Voysey visited the place. A light brown, ferruginous lateritic ore from Tadpalli (Tadpolli) was the chief raw material, but the merits of the steel depended not on this, but on the metallurgical knowledge involved in the carburization and heat treatment of the iron smelted from it.

OTHER IRON ORE DEPOSITS

It is known that there are deposits of haematite near Ratnagiri, in Bombay, and also in Goa. The reserves are said to be of the order of 10 million tons but no reliable estimates are available. The ores are believed to owe their origin to the removal of silica from ferruginous quartzites of Dharwar age. An agreement was announced in October 1951 between a mining company in Portuguese territory and the Konkan Mining Company of Japan, whereby the latter was to install on the former's mine, complete mechanical equipment designed for a maximum daily production of 2,000 tons of iron ore. This is stated to have involved a capital outlay of Rs $1\frac{1}{2}$ crores, some Rs 75 lakhs of which was advanced

to the Konkan Company as a loan by the Export and Import Bank of Japan and repayment for which is to be made by means of a *pro rata* export of ore to Japan. The open-cast mine of Sirigao, 32 miles inland from the port of Marmagao, now fully mechanized by Japanese engineers, was formally opened by the Governor-General of Portuguese India on 13 October 1953. The ore is delivered by chutes from storage bins at the mine direct into barges for water transport to Marmagao, whence it is exported.

Near Narnaul in Patiala, P. N. Bose in 1905 discovered bands of magnetite-haematite ores associated with ferruginous quartzites and granitoid gneisses. Later investigations have revealed reserves of the order of 5 million tons to a depth of 300 feet. Samples contained iron 57.4, alumina 4.8, silica 9.3, phosphorus 0.43 and sulphur 0.15 per cent.

Extensive deposits of magnetite with haematite occur as bands in quartzites in the Chichot subdivision of Mandi, Himachal Pradesh, but as G. Kohli has observed, there are no prospects of these being exploited as long as the high-grade ores of the country are available.

Low-grade, siliceous iron ores, in the form of banded haematite and magnetite quartzites, are common enough in the Dharwars and similar schistose rocks in Peninsular India to make newly recorded finds of little immediate economic concern. This also applies in the case of the ferruginous laterites which, although they often furnished ores for the small local furnaces in times past, are not utilized by the ironmaster of today. The lengthy lists of the iron ore occurrences of practically every State cannot be summarized here, but the interested reader will find them in La Touche's *Annotated Index of Minerals of Economic Value*, and in the *Annual General Reports* of the Directors of the Geological Survey of India, which have appeared since the publication of that work in 1918.

No deposits of high-grade iron ores comparable in any way with those of Peninsular India occur in either Pakistan or Burma, though the low-grade ferruginous laterites of the Salt Range Jurassic sequence, or the similar material at the base of the Eocene in Baluchistan and elsewhere, were worked for small-scale local consumption in the past in some localities. A survey made in 1952 revealed that the Mianwali, Sargodha and Attock districts of West Punjab have workable deposits of iron ore containing about 40 per cent iron.¹

¹ In the North-West Frontier Province, iron ores are known to occur in the Panjkora valley; a large deposit of magnetite has been reported recently from Gowai in Chitral, where haematite also exists in quantity between Sanoghar and Mastey; a band of good, earthy haematite, 5 or 6 feet thick, was noted by Middlemiss on Sorban Hill in Hazara; while in Waziristan, local deposits of haematite and concretionary limonite occur in the Eocene or Mesozoic sedimentary strata.

The Pakistan Industrial Development Corporation has recently concluded an agreement with Krupps for the setting up of a pilot steel plant with an annual capacity of 50,000 tons of iron ingots in 1957, and later another plant capable of producing 300,000 tons of steel yearly at Kot Addu, West Punjab, where a big power station is to be installed by laying a pipe line from Sui to Addu.

The iron ore deposits of Burma are mainly of a lateritic character and are widely distributed throughout the country, forming the basis of the indigenous industry in the times of the Burmese Kings. None of them, so far as is known, offers any prospect of successful large-scale exploitation, especially in the absence of coking coals in the country. For special purposes they have their uses, as instanced by their role in the reduction of the lead ores of Bawdwin, and are obtainable in suitable grades from irregular beds capriciously distributed at the base of the red earths of the Shan Plateau.

It remains to add that manganiferous iron ores are quarried in India for blending purposes; that the nodules of clay ironstone found in the shales of some of the coalfields were for many years used as a source of iron by the Bengal Iron Co. Ltd; that the Travancore titaniferous iron sands are exported in very large amounts as a source of titanium compounds; that in the vanadiferous ores of Bihar and Orissa, the country possesses a potential source of that valuable metal; that certain varieties of massive haematite from Badampahar in Singhbhum and Sandur in Bellary have been found suitable for the production of hydrogen by the water-gas method adopted by the Fertilizer Works at Alwaye in Travancore, though high Indian railway freights make it more profitable to import Spanish ores for the purpose; and that various oxidized ores, often of a lateritic nature, furnish most of the natural red, brown and yellow pigments of the land.

The latest available estimates of the reserves of the major iron ore deposits of India are as follows:

IRON ORE RESERVES

STATE	DISTRICT	TONNAGE		IRON CONTENT
		ESTIMATED	PROBABLE	
Bihar ..	Singhbhum	1,047,000,000	8,000,000,000	Mostly 60 - 68% Fe
Orissa ..	Konjhar, Sundargarh Mayurbhanj, Cuttack Sambalpur, Koraput ..	2,131,000,000 91,000,000 60,000,000		55 - 63% Fe
Madhya Pradesh ..	Drug, Chanda, Bastar	4,482,000,000		60 - 68% Fe
Madras ..	Salem-Tiruchirapalli ..	305,000,000	1,000,000,000	35 - 40% Fe
Mysore ..	Chikmagalur	30,000,000		50 - 60% Fe
	Bellary	138,000,000	300,000,000	45 - 65% Fe
Andhra ..	Anantapur, Kurnool, Cuddapah and Krishna	6,000,000		45 - 65% Fe
	TOTAL ..	8,290,000,000		

The vast quantities of workable, though somewhat lower-grade, ores of Singhbhum are not taken into account in the computation.

PRODUCTION OF IRON ORE IN INDIA, 1900-50

PERIOD	BIHAR AND ORISSA	BENGAL	BURMA	MADHYA PRADESH	MYSORE	OTHERS	TOTAL TONNAGE	TOTAL VALUE (Rs.)	AVERAGE ANNUAL TONNAGE
1900-3	..	252,111	..	..	..	14,400*	266,511	5,81,775	66,628
1904-8	..	383,431†	..	10,949	..	13,134	407,514	10,32,690	81,502
1909-13	..	95,274	59,998	13,058	..	4,564	1,455,286	22,14,330	291,057
1914-18	..	3,447‡	106,532	37,379	..	747	2,149,748	26,11,590	429,949
1919-23	200,014	35,793	16,669§	757	3,510,466	77,67,619	702,093
1924-8	294,595	72,222	156,692	776	8,551,913	2,36,87,815	1,710,382
1929-33	124,337	3,983	135,388	10,943§§	9,893,766	2,19,47,293	1,778,745
1934-8	116,867	3,212	173,037	..	12,492,445	1,98,56,516	2,498,489
1939-43	2,287	236,867¶	2,970	15,338,480	2,75,94,530	3,067,696
1944-8	2,063	184,244	1,382	11,818,552	3,64,38,862	2,363,710
1949-50	1,624	92,166	13,500¶¶	5,773,716	2,80,34,353	2,386,858
TOTAL ..	67,778,145	734,263	902,283	183,470	997,063	63,173	70,658,397	17,17,67,319**	...

* Estimated.

† 286,347 tons from Bengal and 97,084 tons from districts which later became part of Bihar and Orissa.

‡ Ceased in 1915.

§ Started in 1923.

¶ All from Madras.

¶¶ From Bombay.

** Rs 17,17,67,319 = £ 12,882,547 @ Rs 1 = 14. 6d.

THE MANUFACTURE OF IRON AND STEEL

Fifty years ago, about 1900, the average annual production of pig iron in India was approximately 35,000 tons, which came entirely from the works of the Bengal Iron & Steel Co. Ltd. For the five years ending 1950, it averaged 1,532,000 tons in round figures. The manufacture of steel commenced in 1912 and by 1941 had increased to over 1,000,000 tons per annum. Of the grand total of 41,716,412 tons of pig iron made during the present century, 63 per cent was produced by the Tata Iron & Steel Co. Ltd, 30 per cent by the Indian Iron & Steel Co. Ltd, 5.7 per cent by the Bengal Iron Co. Ltd or its predecessors, before its amalgamation with the Indian Iron & Steel Co. Ltd in 1936, and 1.3 per cent by the Mysore Iron Works. Of the grand total of 20,142,893 tons of steel, the Tata concern made 86.3 per cent, the Steel Corporation of Bengal 11.4 per cent, and the Mysore Works 2.3 per cent. Details of the growth of the industries are tabulated in the tables on pp. 199 and 201.

The Indian Iron & Steel Co. Ltd. The early history of the Bengal Iron Co. Ltd has already been mentioned; after various changes of fortune it went into voluntary liquidation in 1936 and was amalgamated with the Indian Iron & Steel Co. Ltd, a company, registered in 1918, which had commenced to smelt iron ores from its own mines at Gua, in Singhbhum, in two 500-ton blast furnaces in November 1922, at Burnpore, near Asansol, 132 miles north-west of Calcutta. The works of the combined concern are at Kulti, the original home of the Bengal Iron Co., and at Hirapur. At Kulti there are now two mechanically charged blast furnaces with a capacity of a quarter of a million tons of pig iron per annum. Coal is carbonized on the spot in four batteries of 132 by-product ovens with an annual out-turn of 200,000 tons of coke, 2,000 tons of ammonium sulphate, 6,500 tons of tar and 300,000 gallons of crude benzol.

The Company has inherited the long-time specialization of the Bengal Iron Co. in the manufacture of cast iron products and large foundries adjoin the blast furnaces, comprising pipe, railway sleeper and general castings sections. A spun-pipe foundry, added in 1945, has an annual capacity of 20,000 tons of cast iron pressure pipes, from 3 to 12 inches in diameter. The combined capacity of all the foundries is about 70,000 tons of finished products of British and Indian Standard specifications. Recent new developments include a heavy pipe factory to turn out 20,000 tons per annum, additional mechanized foundries, and a department for the manufacture of small and medium-sized castings in non-ferrous metals, with a capacity of 400 tons per annum.

The Hirapur works have two 800-ton modern blast furnaces, employing the tunnel system for the conveyance of fuel, and 75-ton ladles which convey the molten metal to two double-strand pig

machines, or to the pig-casting beds as the case may be, while all the finished metal is handled by magnets. The by-product coking installation comprises two batteries, each of 80 Simon-Carvé, horizontal-flue, waste-heat ovens, with a daily output of 1,000 tons of coke; another battery of 40 compound ovens of under-jet type, by the same makers, which add a further 450 tons of coke to the daily out-turn, and additional compound ovens, installed in 1939, and again in 1947, bringing the total coking capacity to approximately 44,000 tons per month. For the recovery of ammonium sulphate, along with the other usual by-products, a contact sulphuric acid plant, capable of making 60 tons of 77 per cent acid daily, has been installed. The Company owns large reserves of coking coal in areas adjacent to the works, though at the present time it derives its supplies from its own collieries at Ramnagar in the Raniganj, and Noonidih, Jitput and Chasnalla in the Jharia field. The composition of some typical products is given below.

ANALYSES OF IRONS MADE BY THE INDIAN IRON & STEEL CO. LTD

FOUNDRY STANDARD	SILICON %	MANGANESE %	PHOSPHORUS* %	SULPHUR %
No. 1 ..	2.75 to 3.25	1.00 to 1.50	0.20 to 0.30	0.030
No. 2 ..	2.25 to 2.75	ditto	ditto	0.035
No. 3 ..	1.75 to 2.25	ditto	ditto	0.040
No. 4 ..	1.50 to 1.75	ditto	ditto	0.050

* Irons with phosphorus contents up to 1.5 per cent are made as required.

The Indian Iron & Steel Co. Ltd and the Steel Corporation of Bengal have extensions in progress with a contemplated out-turn of 800,000 tons of steel ingots per annum. In October 1952 the principle of the amalgamation of the two concerns was approved and negotiations were continued with the Government of India and the World Bank for finance for an expansion programme estimated to cost Rs 31 crores (about £24 million); in the same year the two concerns were merged into a single company.

The Tata Iron & Steel Co. Ltd. The works of this Company, which was founded in 1907 by the enterprise of Jamshedji Nusserwanji Tata, are at Tatanagar, then the small village of Kalimati and now a modern industrial town, covering an area of 25 square miles and lying on the Bengal-Nagpur section of the Eastern Railway, 154 miles west of Calcutta, about 115 miles south of the Jharia coalfield and 45 miles north of the iron ore field of Mayurbhanj and 70 miles north-east of the Singhbhum deposits. Supplies of limestone and dolomite are drawn from quarries at Birmitrapur and Panposh in Gangpur, 117 and 110 miles from the works, respectively.

The original plant had two blast furnaces capable of making 250 tons of pig iron a day, which were 'blown in' in November 1911 and September 1912 respectively, and four open-hearth steel furnaces each of 40 tons capacity. Today there are five blast furnaces with daily capacities of 550, 900, 800, 800 and 1,000 tons, able to deliver some 1,100,000 tons of basic pig iron per annum as well as 15,000 tons of ferro-manganese. The gases from the blast furnaces, before being used in the stoves or under the boilers, are cleaned by modern methods, including a Lodge-Cottrell installation dealing with 15 million cubic feet per hour.

The first coking plant consisted of 180 Evance Coppee non-recovery ovens which were gradually replaced by Koppers, Wilputte and Simon-Carvé types. Today there are three batteries of the last-named, carbonizing 1,300 to 1,400 tons of coal daily. In 1951, the last battery of Wilputte ovens was dismantled and is being replaced by a fourth battery of Simon-Carvés. Over the years 1944 to 1946, the coke production from three Simon-Carvés and one Wilputte battery averaged 847,000 tons together with 37,000 tons of tar and 13,000 tons of ammonium sulphate. A contact sulphuric acid plant produces some 50 tons of 98 per cent acid per day, used for the fixation of the ammonia content of the coke oven gases, for the pickling of steel sheets prior to galvanizing, and in the benzol-toluene plant which provides about 1½ million gallons of these hydrocarbons annually.

The Company manufactures steel by a number of separate processes. In its No. 1 shop there are eight basic, open-hearth furnaces, three of 70 tons, two of 90 tons, and three of 130 tons capacity. The average annual production from these is about 350,000 tons of steel. The Duplex system of steel manufacture, a combination of the acid Bessemer and basic open-hearth processes, is followed in shop No. 2. The plant comprises three 25-ton acid-lined Bessemer converters which receive the molten metal from the blast furnaces, after storage in a hot mixer; their semi-finished, blown product is transferred to three tilting basic open-hearth furnaces, one of 250 tons and two of 200 tons capacity each, for finishing the steel to predetermined composition. The annual production of the Duplex plant is about 650,000 tons per annum. For the manufacture of acid steel, specified for the wheels, tyres and axles of railway rolling stock, etc., the Triplex process is adopted in Shop No. 3, where metal from the blast furnaces is blown in acid-lined Bessemer converters to remove silicon, manganese and carbon as desired, and then charged into a basic open-hearth furnace to be dephosphorized. The dephosphorized steel is then transferred to an acid open-hearth furnace in which the heat is finished. Steel is also made in this shop by the Duplex process or scrap-carbon process. The average annual production since 1942 has been about 42,000 long tons of acid steel, in addition to 16,000 tons of basic steel. There are two 5-ton capacity Héroult-type electric

arc furnaces in Shop No. 1 which are used mainly for the manufacture of special and alloy steels, the average annual output being about 15,000 tons. The manufacture of high-quality alloy, tool and special steels was commenced in 1943 when a separate Tool Steel Plant was inaugurated. It contains one $\frac{1}{2}$ -ton high-frequency induction furnace and ancillary equipment. Two smaller furnaces of the same type used for research purposes are installed in the Research Laboratory.

The rolling mills of the Tata Company are equipped to turn out finished steel products covering practically the whole range of standard requirements. In the blooming mills the steel ingots from the soaking pits are reduced into blooms and slabs. The blooms are then rolled in the continuous sheet, bar and billet mill into sheet bars, tin bars, sleeper bars, billets and so forth, or in the rail and structural mills into rails, beams, angles, channels, etc. The slabs are rolled in the plate mill into steel plates from $\frac{1}{2}$ inch to 3 inches in thickness and to a maximum width of about 7 feet. The various types of bars proceed to their respective finishing mills, and the billets to the Morgan merchant mill, or to other bar mills, to emerge as light structural materials, light rails, fish plates, etc. The sheet mills turn the sheet bars into black sheets of many sizes and gauges, both of ordinary commercial qualities and of special products such as deep drawing sheets, panel plates and high-silicon sheets for the electrical industry; the average annual production of sheets alone amounts to 150,000 tons. Corrugated sheets, either black or galvanized, are produced on rotary machines, and the galvanizing of the black sheets, after pickling in dilute sulphuric acid, is done by the 'hot-dip' process. Pressed steel railway sleepers are made in a separate plant from sleeper bars rolled in the sheet, bar and billet mill. A wheel, tyre and axle plant was installed in 1941 and produces approximately 20,000 tons of such products annually. The Company also makes from its own steel in a separate factory a great variety of agricultural implements and tools such as pick and felling axes, mattocks, crowbars, chisels, *pourahs*, etc.

Amongst the special steels made are two types of low-alloy high-strength materials, known by their trade names of Tiscrom and Tiscor; the former is a high-tensile structural steel of which over 17,000 tons were used in the construction of the new Howrah bridge over the Hooghly at Calcutta. The second is a chromium-copper-silicon-phosphorus steel employed in structural work where great strength and corrosion-resistance, coupled with a reduction in weight, are required. Special steels made to meet urgent demands during the last war, or civilian needs since then, include high-speed tool and shock-resisting steels, material for punches and dies and armour-piercing shells, stainless steel for surgical instruments, magnet steels and high-silicon sheets for electrical machinery, as well as the coinage die steels for the Indian mints. To meet

war-time demands, the Tata Company made over 20,000 tons of bullet-proof plates and other ordnance steels. It also produced such alloys as ferro-tungsten, ferro-vanadium and silico-manganese from Indian raw materials.

The Company has its own plant for the manufacture of magnesia, chrome and other refractories as well as a welding electrode-making plant. Its control and research laboratories are equipped with up-to-date scientific appliances, not only for routine work, but for the investigation of all problems bearing on the production and processing of the ferrous metals and their alloys. A Technical Institute was inaugurated in 1921, for the theoretical and practical training in metallurgy, engineering, etc., of the supervisors and technicians employed in the works.

Many other industries have established themselves in and around Jamshedpur, including The Tinsplate Company of India Ltd, The Indian Steel & Wire Products Ltd, The Indian Cable Co. Ltd, The Agricultural Implements Co. Ltd, and The Tata Engineering & Locomotive Co. Ltd.

A scheme was introduced by the Steel Company in 1933, whereby the employees share a percentage of the profits earned, and by this means labour is associated with the shareholders to the advantage of both. The bonus paid under the scheme for the year 1950-1 exceeded Rs 1 crore.

The present rated capacity of the steel works is about 750,000 tons of finished steel per annum, but the Company has undertaken a programme of expansion and modernization at an estimated cost of Rs 33 crores which will increase the capacity of the plant to 930,000 tons of finished steel per annum. In September 1951, the Company announced its decision to proceed with the manufacture of tubes in association with Messrs Stewarts & Lloyds Ltd, for which purpose, besides the tube mill, a special strip mill for the supply of the necessary skelp will be erected.

In the preparation of this note we have to acknowledge the generous assistance of Mr Phiroz Kutar, General Manager of The Tata Iron & Steel Company Ltd.

Analyses of various basic and foundry grades of pig iron produced by the Tata Company are given on the following page.

The Mysore Iron and Steel Works. The Mysore Government's Iron and Steel Works, where operations were commenced in January 1923, are at Bhadravati, 11 miles east of Shimoga, and consisted originally of a single blast furnace with a capacity of about 60 tons of pig iron daily, together with a wood distillation plant in which the charcoal used as fuel was made and the by-products—wood alcohol, calcium acetate and wood tar—recovered. The main source of the ore supply then, as now, was the Kemmangundi field in the Bababudan Hills, 26 miles to the south; limestone came from Bhandigudda, 13½ miles to the east; the wood supplies from

ANALYSES OF IRONS MADE BY THE TATA IRON & STEEL CO. LTD

GRADE	COMPOSITION			
	Silicon %	Manganese %	Phosphorus %	Sulphur %
Standard Quality (1)	2.75/3.25	1.0/1.5	under 0.40	under 0.035
(2)	2.25/2.75	1.0/1.5	ditto	" 0.05
(3)	1.75/2.25	1.0/1.5	ditto	" "
(4)	1.50/1.75	1.0/1.5	ditto	" "
(5)	1.25/1.50	1.0/1.5	under 0.35	" "
(6)	1.00/1.25	1.0/1.5	ditto	" "
(7)	1.00 & less	1.0/1.5	ditto	" "
Low Manganese Foundry (1)	2.75/3.25	0.5/1.0	under 0.40	" 0.035
(2)	2.25/2.75	0.5/1.0	ditto	" 0.05
(3)	1.75/2.25	0.5/1.0	ditto	" "
(4)	1.50/1.75	0.5/1.0	ditto	" "
(4X)	1.25/1.50	0.5/1.0	under 0.35	" "
Low Manganese Basic Special	1.00/1.25	0.5/1.0	ditto	" "
Low Manganese Basic	1.00 & less	0.5/1.0	ditto	" "
High Manganese Basic	1.00 & less	1.5/1.75	ditto	" "

the adjoining forests. A steel plant consisting of a Siemens-Martin, open-hearth furnace of 25 tons capacity, and a rolling mill designed to finish 20,000 tons of steel per annum, commenced production in 1936, while additional plant was added in 1950.

It has recently been decided, after consultation with Norwegian specialists, to introduce electrical smelting using power from the Jog Falls. Two furnaces, each to produce 100 to 110 tons of iron daily, are contemplated, and these are intended to raise output from 25,000 tons to nearly 100,000 tons per annum. The blast furnace will continue to function but will use coke in place of charcoal.

Two electric furnaces with a daily capacity of 6 or 7 tons were installed at Mysore City during the last war for the manufacture of ferro-silicon, which was supplied to other users in India as required. It is now proposed to make ferro-silicon in a new and larger unit at Bhadravati, and to devote the furnaces at Mysore City to the production of ferro-chrome and similar alloys.

ANALYSES OF MYSORE PIG IRONS

GRADES	Silicon per cent	COMPOSITION
High-Silicon	2.51 to 3.00	In all these grades the content— of manganese varies from 0.50 to 1.00 % of phosphorus is about 0.10 % of sulphur is less than 0.02 % of total carbon is about 3.7 to 4.20 % of combined carbon is about 0.3 to 0.7 %.
Silicon	2.01 to 2.50	
I	1.66 to 2.00	
II	1.26 to 1.65	
III	0.81 to 1.25	
IV	0.51 to 0.80	
V	below 0.50	

The Steel Corporation of Bengal. The Steel Corporation of Bengal Ltd was formed in 1937, with a capital of Rs 5 crores, under the managing agency of Burn & Co. Ltd, Calcutta, to manufacture steel billets, sections, rails, sheets and related products from the pig iron produced at the Hirapur works of the Indian Iron & Steel Co. Ltd. The works of the Corporation are at Napuria, close to those of the Company, and they share common water, electricity and gas supplies. The first steel ingot was cast here in November, 1939. The steel plant comprises both converter and basic open-hearth smelting shops. The mill contains a 40-inch blooming mill, 34-inch and 18-inch section mills, with the usual ancillary equipment-maintenance shops, test house, converter bottom house and laboratory. The capacity of the plant is about 350,000 tons of finished steel annually.

PRODUCTION OF PIG IRON IN INDIA, 1900-50

	Bengal Iron Co.	Tata Iron & Steel Co.	Indian Iron & Steel Co.	Mysore Iron Works	TOTAL TONNAGE	Average Annual Tonnage
1900-3	140,000*	..	..	..	140,000	47,000†
1904-8	209,595*	..	..	..	209,595	41,919
1909-13	241,820*	231,925†	..	..	473,745	94,749
1914-18	381,579	835,185	..	..	1,216,764	243,353
1919-23	491,473	1,355,333	77,525§	9,732§§	1,934,518	386,903
1924-8	481,218	2,847,641	1,490,525	87,651	4,847,035	969,407
1929-33	300,009	3,712,302	1,496,824	87,185	5,596,320	1,119,264
1934-8	125,850	4,512,040	2,742,005	93,382	7,473,277	1,494,655
1939-43	..	5,805,742	3,399,905	134,106	9,339,753	1,867,951
1944-8	..	4,887,263	2,256,622	107,101	7,250,986	1,450,197
1949-50	..	2,067,788	1,128,845	37,786	3,234,419	1,617,210
TOTAL	2,371,544	26,255,219	12,532,706	556,943	41,716,412	..

GRAND TOTAL OF PIG IRON=41,716,412 tons.

Bengal Iron Co.'s ..	..	percentage of total	5.7 per cent
Tata Iron & Steel Co.'s ..	..	" " "	63.0 " "
Indian Iron & Steel Co.'s ..	..	" " "	30.0 " "
Mysore Iron Works' ..	..	" " "	1.3 " "

NOTE :—The Bengal Iron Co. Ltd was amalgamated with the Indian Iron & Steel Co. Ltd in 1936.

* Production of Bengal Iron & Steel Co. Ltd.

† Approximate.

‡ Commenced December 1911.

§ Commenced in November 1922. Figures for 1923 only.

§§ Commenced in 1923.

Hindustan Steel Limited. The articles of association of this Indo-German Company were signed in Delhi on 21 December 1953 on

HUNDRED
THOUSAND
TONS

35

Production of Iron Ore
and Pig Iron since 1900
and Exports of Pig Iron

Tata's production of pig iron
for 1912 and 1913 is distributed
equally over the two years

30

25

20

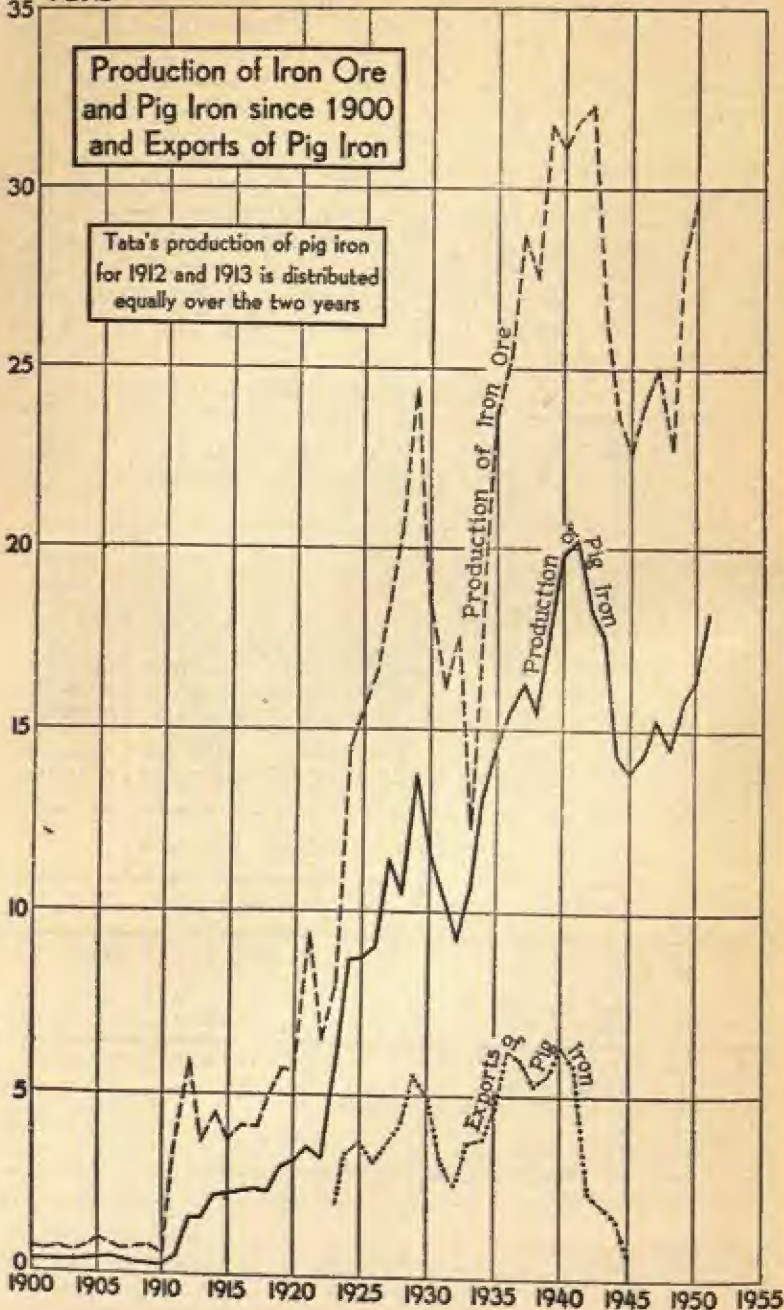
15

10

5

0

1900 1905 1910 1915 1920 1925 1930 1935 1940 1945 1950 1955



behalf of the Government of India and of the German combine of Krupps and Demag. The new company has an authorized capital of Rs 1,000 million and is to erect a steel plant with an annual capacity of 500,000 tons capable of expansion to 1,000,000 tons, at an estimated capital cost of some Rs 71,25,00,000. A site for the plant has been selected at Rourkela in Sundargarh, Orissa and work is expected to commence shortly.

An Indo-Russian agreement for the construction of a steel plant with a capacity of one million tons per annum near Bhilai, Madhya Pradesh, was signed in New Delhi, on 2 February 1955. A British group has offered to erect a third steel plant.

PRODUCTION OF STEEL IN INDIA, 1911-50

	Tata Iron & Steel Co.	Steel Corporation of Bengal	Mysore Iron Works	TOTAL TONNAGE	Average Annual Tonnage
1911-13 ..	63,154*	..	..	63,154	31,577
1914-18 ..	479,930†	..	..	479,930	95,986
1919-23 ..	864,280*	..	..	864,280	172,858
1924-8 ..	1,593,993†	..	..	1,593,993	318,798
1929-33 ..	2,212,854†	..	..	2,212,854	442,531
1934-8 ..	3,243,512	..	40,663‡	3,284,175	656,835
1939-43 ..	3,906,069	803,660§	129,993	4,839,722	967,944
1944-8 ..	3,573,165	1,099,960	148,901	4,822,026	964,405
1949-50 ..	1,441,840	488,651	52,247	1,982,738	991,369
TOTAL ..	17,378,818	2,392,271	371,804	20,142,893	..

GRAND TOTAL OF STEEL=20,142,893 tons.

Tata Iron & Steel Co.'s ..	..	percentage of total steel	86.3
Steel Corporation of Bengal's ..	..	" " " "	11.4
Mysore Iron Works' ..	..	" " " "	2.3

* Ingots.

† Steel including rails.

‡ Commenced in 1936.

§ Commenced in 1940.

THE TRADE IN IRON AND STEEL

During the five years following the first world war, 1919-23, the whole of the Indian Empire of those days imported pig and other forms of crude, metallic iron at the rate of about 31,000 tons yearly, an amount almost identical with that of a still earlier decade. Since those times imports of raw iron have gradually shrunk into insignificance, and the few hundred tons which still appear in the Customs Returns probably represent special varieties imported for particular purposes. While this change was taking place India became an exporter of metallic iron, and even before the first world war had shipped her own homemade product to Burma, the Straits

Settlements, Ceylon, Java, Manchuria, China, Japan, Australia, New Zealand, the Pacific Coast of the United States and South America. As a matter of historical importance it should be recorded that during the first world war the export of both iron and steel from India was prohibited by the Government of the day, and the whole output of steel rails taken for use in the campaigns in Mesopotamia, East Africa, Palestine and even as far away as Greece. Shell steel was supplied to the Indian munitions factories, and both the iron-producing companies then in existence made ferro-manganese on a large scale. Post-war conditions interfered for some years with the resumption of the export trade in pig iron on its former scale, but it slowly recovered and averaged some 379,000 tons per annum over the decade ending 1933, and rose to over half a million tons (519,850) yearly in the next quinquennium, 1934-8. The years of the second world war witnessed a decline to an annual average of 442,600 tons over the years 1939-43, followed by an exceedingly steep drop to 85,468 tons, the average for the three years 1944-6, while the average for the two years 1948 and 1949 was but 49,383 tons. The record year was in 1940 when 627,099 tons of pig iron were shipped abroad. Of the grand total of 8,860,166 tons of pig iron, valued at Rs 37,07,01,336, exported during the 23 years 1924-46, 48.1 per cent went to Japan, 32.2 per cent to the United Kingdom, 11.5 per cent to the United States of America and the remaining 8.2 per cent to many other lands, including China and Germany.

As the details given in the table opposite demonstrate, India still imports vast quantities of capital goods in the form of iron and steel pillars, girders, bridge work, bolts and nuts, nails, hoops, strips and fencing materials as well as railway track materials and fittings, to say nothing of machinery of all descriptions and consumer goods such as cutlery and hardware. In the pre-war quinquennium, 1934-8, these cost the country about Rs 21 crores annually, excluding what was spent on railway plant and rolling stock. Over the seven years 1939-45, the total value of such imports was still over Rs 17 crores, and on the conclusion of the war the figures rose to considerably more than Rs 35 crores in 1946. Taking fabricated iron and steel articles alone, and leaving out of consideration all forms of machinery, hardware and cutlery, 273,852 tons were imported annually over the five years 1934-8; contraction during the war was inevitable and severe, but by 1949 such imports were back to 179,000 tons and in 1950 had risen to 317,000 tons, valued at Rs 16 crores. This expenditure, as Dr M. S. Krishnan has written, 'can be eliminated only by immediately putting into effect a large expansion programme of the iron and steel industry'. The Five-Year Plan announced in July 1951 envisages an increase in steel production from the present annual total of some 1,005,000 tons to 1,315,000 tons by 1955-6. Whether this will then satisfy internal demands remains to be seen. It is

IRON

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AVERAGE ANNUAL IMPORTS OF IRON AND STEEL, 1914-46

	1914-18	1919-23	1924-8	1929-33	1934-8	1939-45	1946
Cutlery and hardware ..	Rs 3,54,20,070	7,00,57,822	5,68,41,372	3,96,06,660	3,31,62,058	1,91,26,417	4,13,19,418
Machinery and millwork ..	Rs 5,40,11,565	22,31,18,902	16,84,91,502	15,55,51,821	14,85,08,811	13,37,08,070	29,51,95,783
Railway plant and stock ..	Rs 5,42,29,755	14,31,94,046	6,74,70,501	....	....	....	....
Iron bars, pig iron, etc. ..	Rs 47,64,090 Tons 23,425	71,92,301 31,120	26,09,415 16,678	9,70,093 7,098	4,94,565 3,581	1,93,493 880	1,46,086 345
Iron or steel beams, etc. ..	Rs 8,29,67,164 Tons 300,473	16,91,52,163 443,629	17,17,19,344 795,102	8,57,72,791 457,635	66,97,442 37,317	33,35,404 7,810	55,34,150 6,035
Steel angles, bars, etc. ..	Rs 1,47,32,760 Tons 74,143	3,87,59,033 163,143	2,64,00,149 242,958	1,47,22,708 136,312	1,01,24,099 80,525	67,29,800 34,989	60,89,564 17,367
Iron or steel bolts, etc. ..	Rs Tons ....	.... ....	.... ....	.... ....	1,01,95,562 56,020	81,87,283 22,904	47,48,220 11,144
Total ..	Rs 24,61,25,404	65,14,74,267	49,35,32,283	29,66,24,073	20,91,82,537	17,12,80,467	35,30,27,621

Notes:—

* Iron or steel beams, etc., includes channels, sheets, pillars, nails and rivets.

* Steel angles, bars, etc., includes tees, springs, ingots and blooms.

* Iron or steel bolts, etc., includes nuts, hoops, strips and fencing materials.

Imports of fabricated iron and steel, excepting machinery, hardware and cutlery, had risen to 179,000 tons in 1949 and 317,000 tons, valued at over Rs 16 crores, in 1950. Their value in 1951 was more than Rs 20 crores.

neither a large amount judged by the fact that 'steel forms the skeleton framework within the body of modern civilization', nor by its equivalent of 1,336,040 metric tons, compared with the 1950 production of other steel-making nations as expressed in metric tons as follows: the United States 87.7, the Soviet Union 27.6, the United Kingdom 16.6, Western Germany 12.1, France 8.7, Belgium and Luxembourg 6.2 and Japan 3.8 millions. As far as natural resources are concerned, India with her immense deposits of iron ore and manganese (which is just as essential in making steel as limestone or coke), can expand her ferrous industries in any direction considered desirable. These resources are far greater than those of any other Asiatic country. A great and rapidly growing home market exists for steel products of every description. Her geographical position gives easy accessibility to the markets round the Indian and Pacific Oceans. Her ironmasters, steel-founders and technicians are men of great metallurgical skill and commercial ability. All these things presage expansion in the future.

MANGANESE

The world's production of manganese ores averaged about 4,850,000 tons per annum over the five years 1934-8 and in normal times the demand for the ore rises and falls with the fortunes of the iron and steel industry, in which about 90 per cent of the output is consumed; a further 5 per cent is used for non-ferrous alloys and the remainder for chemical purposes. The world's output of steel expanded from about 13 million tons per annum in 1890 to over 132,000,000 tons in 1937, and over the same term of years the annual yield of manganese ores increased from less than half a million tons to more than six million tons, a march of progress in which India's manganese ore deposits played no inconsiderable part.

Employed to some extent in the manufacture of pig iron, the element is used chiefly in the form of ferro-manganese and spiegel-eisen as a purifying agent in deoxidizing, desulphurizing and re-carbonizing steel, and, having performed these indispensable functions, most, but not all of it, passes into the waste slags. For these purposes it is essential and has no substitute. To the genius of J. M. Heath, a servant of the East India Company who resigned his appointment to develop the iron and steel industry in south India, are due those earliest successful experiments with manganese which, in the words of an American authority, completely revolutionized the steel industry of England and through it of the whole world. Practically all steels contain manganese, usually ranging around 0.5 per cent; high-tensile structural steel may contain from 1.3 to 1.6 per cent, and rail steel from 0.9 to 1.2 per cent. Sir Lewis Fermor has stated recently that for every ton of steel produced some 60 lb. of high-grade manganese ore are necessary.

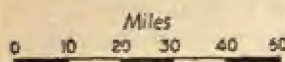
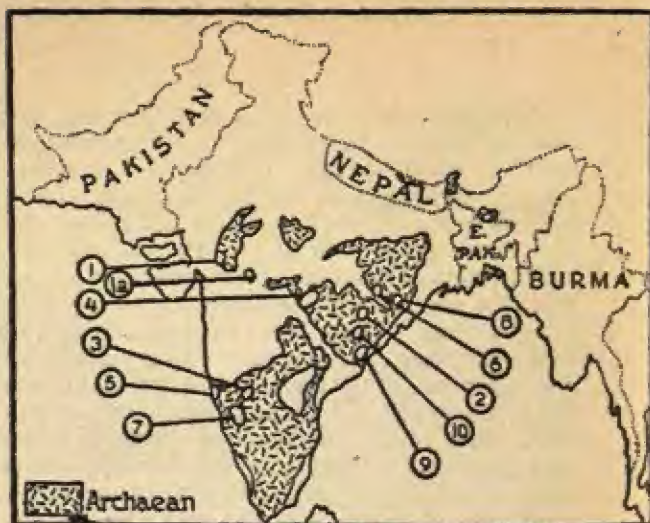
Manganese steels with 12 or 13 per cent of the metal, besides being practically non-magnetic, are exceedingly hard and tough, qualities which account for their uses in many types of mining, milling, dredging and digging machinery, such as rock crushers, buckets and tumblers, excavators and railway and tramroad points and crossings, as well as in light armour for aircraft and such articles as steel helmets. Manganese also enters into the composition of a number of alloy steels containing chromium, nickel and molybdenum. The alloys of manganese and copper serve many useful purposes, as for example in turbine blades, which contain 4 or 5 per cent of the metal. 'Manganese bronze' is a high-grade brass, toughened and strengthened with 3 or 4 per cent of manganese, which resists corrosion and is used in marine engineering for ship propellers as well as in the chemical and brewing industries. Another alloy of copper, with 8 to 12 per cent of manganese and 4 per cent of nickel, is drawn into wires for electrical resistances. The commercial manganese-aluminium alloys contain from 0.5 to 3 per cent of manganese; one type with 1.25 per cent manganese is used in the manufacture of aircraft tanks, hollow ware and the bodywork of transport vehicles; another with 4 per cent copper, 0.5 per cent magnesium and 0.5 per cent manganese has been largely used in the construction of many types of aircraft, especially when clad with a coating of pure aluminium.

The peroxide ores of manganese are the starting-point in the manufacture of the metal itself by the aluminothermic process, and some of the Indian ores of this type yield a satisfactory commercial grade of metal without recourse to wet chemical methods. Their chief use, however, is in the make-up of dry batteries and cells of the Leclanché type, in which they act as depolarizers. They can be employed in the manufacture of bromine and iodine, certain organic chemicals, as well as the disinfectants sodium and potassium permanganate and sodium manganate. Manganese ores have been in use in India from very early times for colouring glasses and enamels green, violet, brown and black, and they are still employed throughout the world both as decolorizing and as tinting agents. In the former case the right proportion of manganese neutralizes the green colour due to ferrous salts (see under GLASS SANDS); in the latter they impart purple, chocolate, grey and black colours to the bodies or the glazes of bricks, tiles and pottery wares. Certain organic compounds of manganese are widely used in the paint, oil and varnish industries as drying agents of vegetable oils. Finally, the sulphate and acetate of manganese are valuable fertilizers, especially for neutral soils and for alkaline soils which are deficient in available manganese.

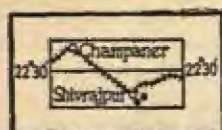
HISTORY OF THE INDUSTRY

The Indian manganese industry dates from 1891, when a syndicate was formed to open up the Kodur deposits of the Srikakulam

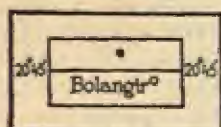
MANGANESE ORE-BEARING AREAS



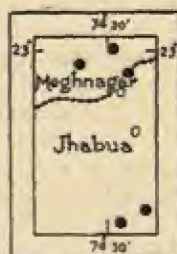
Scale of insets



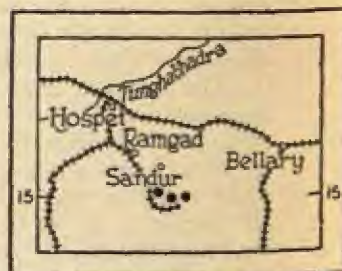
1. PANCH MAHALS
(Bombay)



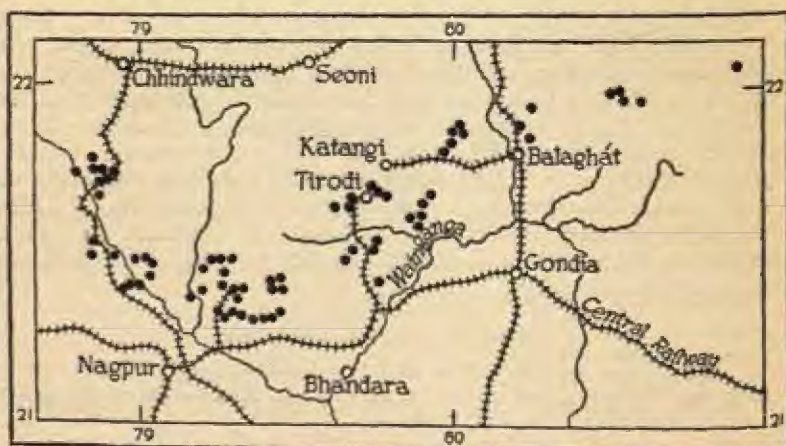
2. BOLANGIR (Orissa)



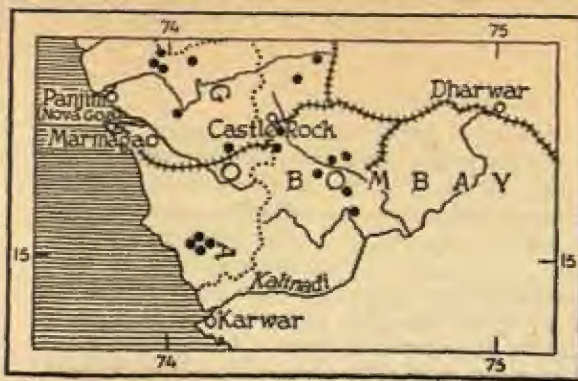
1a. MADHYA
BHARAT



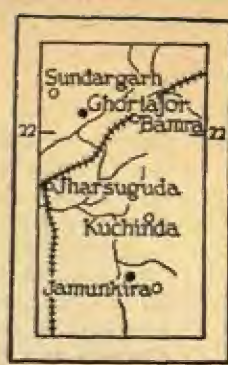
3. SANDUR (Mysore)



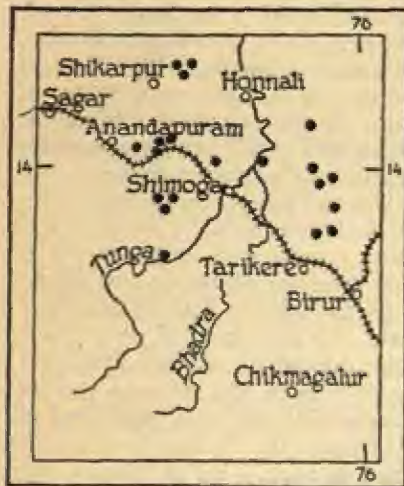
4. MADHYA PRADESH



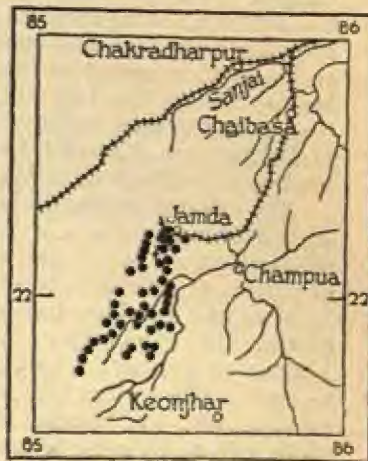
5. GOA & N. KANARA (Bombay)



6. GANGPUR
BAMRA (Orissa)



7. MYSORE



8. BONAI : KEONJHAR
(Orissa) & SINGHBHUM
(Bihar)



9. SRIKAKULAM (Andhra)



10. KALAHANDI :
RAYAGADA (Orissa)

including hollandite, jacobsonite, sitaparnite and pyrolusite. The exact chemical constitution of some of these minerals is still uncertain, but psilomelane, the most abundant of all Indian manganese minerals, and, with braunite, forming probably at least 90 per cent of the exported product, includes both psilomelane proper, a manganate of manganese and barium with essential water, and cryptomelane, a manganate of manganese and potassium. It is probable that both components are present in the Indian mineral usually termed 'psilomelane' and its content of metallic manganese may be as low as 45 per cent or as high as 60 per cent. Braunite is a twin compound of the oxide and silicate of manganese, $3\text{Mn}_2\text{O}_3 \cdot \text{MnSiO}_3$, often with part of the manganese in the oxide replaced by iron. After psilomelane it is the most abundant of the manganese ores of India, with 52 to 58 per cent of manganese and from 1 to 10 per cent of iron. Hollandite is another manganate of manganese, iron and barium, closely approaching psilomelane in composition, but differing from it in being, as a rule, anhydrous. It contains from 45 to 56 per cent of manganese and 3 to 7 per cent of iron. Jacobsonite is a member of the spinel group of minerals with the chemical formula $(\text{Fe.Mn.Mg})\text{O} \cdot (\text{Fe.Mn})_2\text{O}_3$, which when intergrown with hausmannite, the oxide of manganese Mn_2O_3 (manganese 72 per cent), forms the ore known in India as vredenburghite. Sitaparnite, another Indian speciality, is thought by some mineralogists to be a relative of bixbyite, $\text{MnO}_2 \cdot \text{FeO}$, with lime; others give its formula as $(\text{Mn.Fe})_2\text{O}_3$ with CaO , containing 44.09 per cent of manganese and 19.32 per cent of iron. Pyrolusite is the dioxide of manganese usually with a little water; it is sometimes pseudomorphous after manganite, $\text{Mn}_2\text{O}_3 \cdot \text{H}_2\text{O}$, but with the atomic structure of polianite, another dioxide, and it contains 63.2 per cent of manganese.

The bedded manganese ores of India, like those of Brazil, the Gold Coast and South Africa which are of similar Archaean age, were originally sediments, some of which contained varying proportions of manganese. As a result of regional movements, and profound metamorphism intensified in some cases by the contact effects of later intrusions, the primary sands and clays were changed into quartzites, phyllites, and mica schists: the purer manganese-bearing sediments into crystalline manganese ores and the mixtures into the distinctive rocks to which Fermor gave the name of 'gondites'. True gondite is a rock made up of the manganese garnet, spessartite and quartz, but spessartite rock itself, rhodonite rock and rhodonite-quartz rocks are also common; rhodonite being the silicate of manganese MnSiO_3 . Since their discovery in India gondites have been identified in both the Gold Coast and Brazilian manganese ore deposits and, apart from giving clues to the origin of the ores, they are important because as a result of surface oxidation changes they can give rise to deposits of manganese ores.



OPENING UP A MANGANESE ORE DEPOSIT

In Madhya Pradesh particularly, but to some extent elsewhere, the primeval sediments were rich enough to form manganese ores of the braunite-sitaparite-hollandite type, possibly with pyrolusite, on metamorphism, while some of them, intruded by pegmatites, have recrystallized as braunite; the jacobsonite-hausmannite types of ore may have had a similar origin. Under the prolonged action of weathering, acting downwards to considerable depths, the manganese minerals mentioned have been largely altered to psilomelane-pyrolusite mixtures while the silicates of the gondites themselves have yielded psilomelane, pyrolusite and possibly braunite. These are not theoretical speculations, for the various stages in the transformations are often clearly visible, and the orebodies, well bedded as they are to the prevailing rock strike, can be seen passing into fresh representatives of the gondite series.

In the Nagpur-Balaghat region the orebodies form lenticular masses and bands intercalated in quartzites, schists and gneisses, often disposed along the same line, as, for instance, in the Nagpur district where they stretch from Dumri Kalan to Khandala, a distance of twelve miles, and include the valuable deposits of Beldongri, Lohdongri, Kacharwali and Waregaon. They frequently attain huge dimensions. Thus the Balaghat deposit is $1\frac{1}{2}$ miles long, another at Manegaon, in Nagpur, $1\frac{1}{2}$ miles long, while the band running through Jamrapani, Tirodi and Ponia, in Balaghat, is exposed more or less continuously for six miles. Equally impressive are the large amounts of ore yielded by some of these single deposits and particularly by Tirodi, Balaghat, Chikkla (in Bandhara), Kandri, Mansar (in Nagpur) and Kachhi Dhana (in Chhindwara), which by the end of 1938 had given 2,219,921, 1,881,594, 1,158,416, 1,376,726, 1,099,465 and 922,214 tons respectively. Many of them originally formed small hills which favoured exploitation by the simpler forms of quarrying, indeed, most of the ore is still won by open-cast methods, ranging from shallow surface workings to deep quarries, and at only four localities has it yet been necessary to adopt underground methods: these are at Kandri and Mansar in Nagpur, Bharwali in Balaghat and at Shivrajpur, in the Panch Mahals of Bombay. Diamond drilling at the Balaghat mine in 1949 and 1950 has proved that orebodies of these types extend to considerable depths, and contain ores of excellent quality to these depths in sufficient quantities to maintain outputs for very many years to come. Gondite ores generally are of the first grade with a manganese content of over 48 per cent, together with moderate quantities of second-grade material containing 45 to 48 per cent of the metal.

The manganese ores of the second group are associated with the kodurites, a name given by Fermor to a series of rocks, found in the Srikakulam district of Andhra and in Orissa, associated with other crystalline Archaeans, and ranging from ultra-acid types such as quartz-orthoclase rock at one end of the series to

ultrabasic varieties at the other. Typical kodurite, the basic member of the series, is composed of potash feldspar, spandite (a garnet intermediate in composition between the manganese garnet, spessartite, and the calcium-iron garnet, andradite) and apatite. The exact origin of these rocks is doubtful and varied opinions about them have been advanced by Fermor, P. Sampat Iyengar, Dunn and others, but whatever it may have been, they have been greatly altered since their formation, with the production of lithomarges, manganese ores and secondary products such as chert, ochres and wad. Their orebodies are commonly extremely irregular, but occasionally, as at Garbham in Sriakakulam, possess a well-developed dip and strike. Some of them are of great size; Garbham itself was the largest, with a length of 1,600 feet and a width of 167 feet at its thickest section, 100 feet of this being ore and the remainder lithomarge and wad; between 1896 and 1938 it gave 1,010,561 tons of ore. The Kodur deposit of this group, with an output of 417,711 tons between 1892 and 1938, has the distinction of being the first to be mined in India. The ores generally are for the most part psilomelane with subordinate pyrolusite, braunite and manganomagnetite ($(\text{Fe.Mn})\text{O.Fe}_2\text{O}_3$), though at Garividi the mixed jacobsonite-haumannite, known as vredenburghite, occurs. They are, as a rule, second- and third-grade ores characterized by high iron and phosphorus contents and comparatively little silica.

The lateritoid deposits are secondary surface replacements, often found on rocks of Dharwar age, resembling laterite in their irregular structures, their radiating, botryoidal and stalactitic-like habits easily betraying their origin. They invariably contain high percentages of iron and often grade through ferruginous manganese ores and manganiferous iron ores into iron ores proper. Their manganese minerals are pyrolusite, psilomelane, wad (soft amorphous mixtures of impure oxides of manganese, passing into psilomelane) and, more rarely, pseudo-manganite ($\text{Mn}_2\text{O}_3 \cdot \text{H}_2\text{O}$), passing into pyrolusite: their iron contents take the forms of limonite and earthy haematite. The chemical characteristics of ores of this group are high iron, low manganese, low silica and often very low phosphorus contents, and they are usually classified as second-grade manganese ores and third-grade ferruginous manganese ores. They have been won for the most part in Bellary district, once part of Madras but now in Mysore, where on one property alone, that formerly of the General Sandur Mining Co. Ltd, A. K. Dey has estimated there are still about 800,000 tons available.

Of the replacement or segregation deposits, which often underlie such irregular lateritoid deposits, those of Dhubna and Jampani, in Keonjhar, are good examples. Here, lenticular bodies and pockets of ore, up to 400 feet in length and 10 to 20 feet in thickness, containing reserves of about half a million tons, have been formed at the junction of shales with haematitic iron ores. The lower

grade ores of the Liligumma *zemindari* of Kalahandi, on the other hand, are associated with khondalites and hypersthene-bearing rocks, but in the Kashipur area there may be about 100,000 tons of better quality material. Thin veins and small lenses of psilomelane occur in a shear zone in steeply dipping Cumbum shales near Janapalacheruvu in the Kurnool district of Andhra. The manganese ores of Goa occur as pockets in manganiferous, ferruginous shales enriched by lateritization and recalling similar deposits in the Jamda area of Singhbhum. A fair proportion of the ores from the Sanguem district are of chemical grade with low phosphorus and silica contents. In the Bardez, Sanguem and other districts of western Goa, manganese ores associated with high-grade iron ores are mined from thick laterite formations. Over the years 1947 to 1949, 17,261 tons of manganese ores were won in Goa. Several small scattered occurrences of manganese ores are known in the adjoining districts of Bombay, varying in the amount of their reserves from about 10,000 to 120,000 tons.¹

At Hopong, in the Southern Shan States of Burma, 3,000 tons of ores of a pyrolusitic character were won by the Japanese during the occupation, and a further 3,000 tons approximately were produced in 1950. One orebody is about 200 feet in length with a width of 50 feet or so of good ore and appears to be surrounded by material with a much higher iron content, and then by soft, manganiferous earth containing some limestone and traces of rhodochrosite. Other occurrences probably exist in the same neighbourhood and seem to be related in origin to the residual iron ore deposits of the *terra rossa* of the Shan States.

Indian ores containing over 48 per cent of manganese are classified in the first grade, those containing between 45 and 48 per cent in the second grade, and ores with less than 45 per cent as third-grade material. In Bihar, however, this system is not adopted and all ore with less than 48 per cent manganese is either sold at second-grade prices, or marketed on its analysis. Some qualities ranging down to 32 per cent of manganese and up to 17 per cent of iron are disposed of as manganese-iron ores to the iron and steel manufacturers. Analyses of typical ores as shipped in 1946 are given in the table on p. 214.

THE INDIAN MANGANESE ORE TRADE

India's chief competitors in the manganese ore trade of the world for many years were Russia and Brazil, but entering the business in 1891, she had displaced Russia from the leading position by 1907, with a production of 902,291 tons, and continued to maintain her lead until 1912, when the relative positions of the

¹ In West Pakistan, four small deposits of low-grade manganese ore, containing a total estimated quantity of some 500,000 tons, have been located recently in the States of Las Bela and Kalat, according to the ECAFE Report, 1953.

two countries were reversed. The first world war (1914-18) paralysed the Russian industry and affected the Indian one to some extent, while Brazil and the United States greatly improved theirs, though insufficiently to oust India from the premier position which she had regained in 1916. During this period, 1914 to 1918, the average annual output was 577,457 tons, but exports were limited by shipping shortages so that by 1919 over 300,000 tons of ore were stocked in the country. It was about this time that a number of new competitors appeared, particularly Egypt, Cuba and the Gold Coast, the ore from the last being in part first-grade quality with 51 to 52 per cent manganese.

ANALYSES OF INDIAN MANGANESE ORES

MINE	Mn	Fe	SiO ₂	P	MnO ₂	REMARKS
MADHYA PRADESH						
Balaghat ..	51.0	7.0	6.5	0.10	55.0	Mine ore
" ..	48.5	8.0	5.5	0.06	45.0	Boulder ore
Bhandara ..	50.5	7.5	8.0	0.16	28.0	Mine ore
" ..	49.5	7.5	7.0	0.08	34.0	Boulder ore
Dongri ..	51.25	6.5	3.5	0.275	75.0	Run of Mine ore
" ..	59.0	1.0	1.0	0.29	90.0	Low ferruginous peroxide ore
" ..	58.5	2.75 max.	2.0 max.	0.32	88.5	Standard peroxide ore
BOMBAY						
Shivrajpur ..	48.50	4.5	6.8	0.23-0.26	..	First-grade ore
" ..	46.47	5.7	9.11	0.24-0.28	..	Second-grade ore
" ..	43.44	6.8	12.14	0.24-0.27	..	Third-grade ore
ORISSA						
Keonjhar ..	49.0	8.56	4.40	0.135	..	First-grade ore
" ..	45.8	8.18	5.25	0.165	..	Second-grade ore
" ..	40.0	13.80	5.70	0.047	..	Third-grade ore
" ..	..	0.16	0.40	..	91.96	Manganese dioxide ore, First-grade
" ..	..	0.91	0.95	..	88.0	Manganese dioxide ore, Second-grade
MYSORE						
Sandur ..	40.2	16.40	1.2	0.02	56.5	Low-grade ore

Analyses kindly supplied by the following Companies: the Central Provinces Manganese Ore Co. Ltd, the Shivrajpur Syndicate Ltd, Bird & Co. Ltd, and the General Sandur Mining Co. Ltd.

In the first quinquennium following World War I, that is to say over the years 1919 to 1923, India maintained her lead with average annual exports of 624,635 tons, compared with Brazil's 297,497 tons and Russia's 170,000 tons, while Egypt and the Gold

Coast followed closely in the fourth and fifth places. Improvement continued over the next five-yearly period, 1924 to 1928, with an annual average production of 953,037 tons and a peak of 1,129,353 tons in 1927, but the Russian industry was recovering its lost ground, rising to an average of 730,279 tons, while Brazil fell away to 263,675 tons and the Gold Coast occupied the fourth place with 352,232 tons.

The years 1929 to 1933 were particularly remarkable, for from the world's highest recorded output of 3,598,343 tons in 1929, production slumped to 1,218,879 tons in 1932, the lowest figure for many years. The results were disastrous. The Indian annual average dropped 41.4 per cent to 558,596 tons, the Brazilian by 50 per cent to 127,175 tons, the Gold Coast fell to 279,947 tons, but Russia continued to recover and finally displaced India from her leading position. It was during this period too, that South Africa, another formidable competitor of India, entered the world's markets. By 1932 the collapse of the trade had reduced the level of Indian production to that of 37 years earlier and while the output in 1933 (218,307 tons) was a little over one fifth that of the peak year of 1927 (1,129,353 tons), its value (£123,171) was about one twenty-second part of the same (£2,703,068). It is not surprising that a number of mines were closed down and some companies forced into liquidation.

Prosperity returned in the next period, 1934-8, when India's annual average tonnage increased to 776,151 tons, with a new peak of production of 1,051,954 tons in 1937 and exports of 1,151,834 tons in that year, a record not only for India but for the world. Notable too was the rapid rise of the new port of Visakhapatnam (Vizagapatam), which from 1935 took the lead as an exporting harbour and was followed by Calcutta, Marmagao and Bombay.

The effects of the second world war were not strikingly marked over the years 1939 to 1943, the annual average tonnage remaining much the same at 771,471 tons, but thereafter, shipping difficulties and shortage of rail transport became acute so that output for the three years ending 1946 averaged only 278,160 tons. An improvement was registered in 1947 and 1948 and the quinquennium closed with an annual average of 362,277 tons.

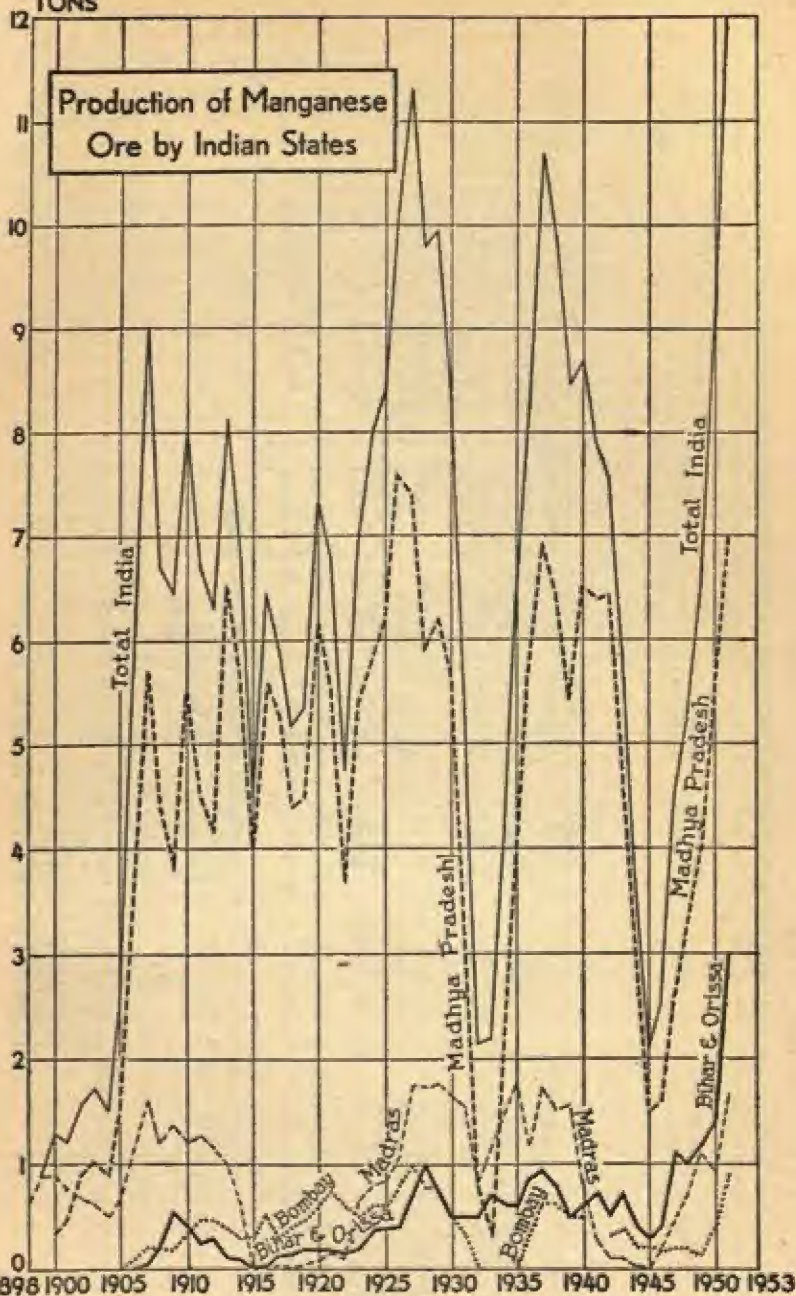
The years 1949 and 1950 were prosperous ones again, as the rearmament projects of the Atlantic Powers, with their concomitant demands for greater supplies of steel, as well as stock-piling operations particularly in the United States of America, gained momentum. As a result there was an increase of almost 23 per cent from a production of 525,876 tons in 1948 to 645,825 tons in 1949, followed by a further expansion of nearly 40 per cent to 901,609 tons in 1950 and to a new record of 1,283,929 tons in 1951.

Of the 16,252,000 tons of manganese ore shipped from 1895 to 1931, but excluding the exports from Marmagao, in Portuguese India, the destinations of which are not known, exactly 40 per cent went to the United Kingdom, 21·3 per cent to Belgium, 17·16 per cent to France and 15·38 per cent to the United States of America. The countries taking smaller quantities included : Holland 2·11 per cent, Italy 1·16, Germany 1·39 and Japan 0·71 per cent. Between the years 1932 and 1946, a further 7,727,000 tons went to foreign lands, and of this quantity the United States received 37·9 per cent, the United Kingdom 24·4, Japan 15·1, France 10·7, Belgium 6·4, Italy 1·6, Germany 0·7 and other countries 3·2 per cent. In these figures the shipments from Marmagao are included from 1942 onwards. Exports to enemy countries ceased with the second world war, and the most noteworthy features of the war period were the decline in exports to the United Kingdom and their increase to the United States, a feature of the trade which still continues, for of the 1,601,450 tons exported in the three years 1948-50 inclusive, just two-thirds was destined for the United States and approximately one-third to the United Kingdom and other countries. During their brief occupation of Burma, the Japanese are said to have mined some 3,000 tons of manganese ore from a surface deposit in the Hopong State of the Southern Shan States, but little is known at present of the nature of this occurrence.

Madhya Pradesh is by far the most important producing region and was responsible for no less than 69 per cent of the total Indian production of 31,685,758 tons up to the end of 1950; Madras including Andhra came next with 14·5 per cent and was followed by Bihar and Orissa with 7·8, Bombay with 5·4, Mysore with 2·6 and Madhya Bharat (Central India) with 0·7 per cent of the total, respectively.

The prosperity of the export trade, apart from its ability to deliver manganese ores at the sea-ports at competitive market prices, which in India is largely a question of labour costs and railway freight charges, depends entirely on the world's demand for steel. There is no better illustration of this than the prevailing conditions of the great depression of 1929 to 1933; in 1929 the world's output of steel had reached 118 million tons, the highest figure recorded up to that time, and the world's output of manganese ores attained a record of 3,598,343 tons, to which India contributed 994,279 tons, or 27·6 per cent. By 1932, the world's steel production had dropped to 49·7 million tons and the world's output of manganese ores to 1,218,879 tons, of which India's share was 212,604 tons or 17·4 per cent. Over the same period the market price of manganese ore fell from 14·0 pence per unit in 1929, to 9½ pence per unit in 1932. In the same manner the improvement in the Indian trade which followed later was but a reflection of the revival in steel manufacture, itself accelerated

HUNDRED
THOUSAND
TONS



PRODUCTION OF MANGANESE ORES IN INDIA, 1892-1950

PERIOD	BIHAR AND ORISSA §	BOMBAY	MADHYA BHARAT	MADHYA PRADESH	MADRAS (ANDHRA AND BELLARY DISTRICT)	MYSORE	TONNAGE TOTAL	EXPORT VALUES (f.o.b.)	PERCENTAGE OF WORLD'S PRODUCTION
1892-8 ..	..	..	6,800*	..	225,346	..	225,346	233,845	....
1899-1903 ..	..	..	140,946	312,621**	384,378	..	703,799	873,175	....
1904-8 ..	23,993	54,213†	42,773	1,584,523	513,845	228,243††	2,545,718‡	3,386,595	50.6 (1908 only)
1909-13 ..	160,358	178,360	42,773	2,442,424	598,488	141,401	3,563,984	4,227,025	40.7
1914-18 ..	37,662	175,216	7,008	2,479,402	66,973	121,023	2,887,384	6,276,651	34.1
1919-23 ..	102,267	266,475	..	2,527,011	98,910	108,513	3,123,176	9,473,413	44.1
1924-8 ..	282,622	267,198	27,783	3,992,796	624,566	160,232	4,765,197	12,497,315	33.6
1929-33 ..	290,613	160,304	..	1,582,666	598,962	60,435	2,792,980	3,761,413	....
1934-8 ..	467,431	155,222	..	2,431,652	762,720	13,729	3,880,794	8,625,391	....
1939-43 ..	463,990	165,640§§	..	2,943,723	280,696	3,308	3,857,357	8,071,809	....
1944-8 ..	334,197	97,817¶	4,837	1,213,957	137,664	2,937	1,811,409	3,468,471	....
1949-50 ..	308,388	66,708¶¶	2,833	938,075	207,127	5,623	1,528,754	9,304,039	....
TOTAL ..	2,491,661	1,707,153	232,980	21,808,850	4,599,655	845,444	31,685,758	70,199,042	....

GRAND TOTAL to end of 1950, 31,685,758 tons, valued at £70,199,042.

* Production commenced in Madhya Bharat in 1903.

** Madhya Pradesh in 1900.

*** Bengal (later Bihar & Orissa) in 1906.

† Bombay in 1905.

†† Mysore in 1906.

‡ Includes 15 tons from the Pab Hills, Jhalawan, Pakistan.

§ the Eastern States from 1934.

§§ 19 tons from Rajasthan.

¶ 4,393 tons from Rajasthan.

¶¶ 16,576 tons from Banswara, Rajasthan.

by the preparations for war, increased, then as now, by the purchases of reserves of minerals of munitions value which nations collect for use in emergencies.

The reserves of high-grade manganese ore in India have been conservatively estimated at 18 million tons, while lower-grade ores may amount to twice this quantity. In all probability appreciable increases will have to be made in these figures, as the diamond drilling campaign initiated of recent years in Madhya Pradesh is extended both there and elsewhere, not to mention the possibility of entirely new discoveries.

India's first concern is the conservation of sufficient supplies of high-grade ore to meet the demands of her own expanding iron and steel industry and steps have already been taken in this direction. For the year 1950, a target of 700,000 tons of high-grade ore was fixed as the official maximum quantity against which export licenses were issued, though the export of lower grades was permitted without limit. If requirements in the next few years are placed at 110,000 tons per annum, or double the pre-war consumption, there is more than enough for many years to come, but the more distant future must be borne in mind, as it is within the country's power to become a very large producer of steel. This is the problem which must ultimately decide how far it is desirable for India to compete in the world's market for manganese ores. Here, it can only be stated that India is extremely unlikely to suffer from a shortage, that external demand will always be keen when the world needs steel, and that there is no apparent reason why the industry should not surpass its former peaks of production, provided that the long-term planning authority of the State considers it politic for it to do so. Stricter attention should be paid in future to the introduction of modern concentration methods, to recover ore from low-grade materials and from the spoil heaps which have accumulated from the wasteful methods of the past. Finally, the most profitable possibilities lie in the production of ferro-manganese in India and its export in that form rather than as the raw ore. As Dr J. A. Dunn pointed out: 'With low manganese-ore production costs and low freight charges, India should be well able to compete in the ferro-manganese trade.'

FERRO-MANGANESE

Over forty years ago, in 1909, Sir Lewis Fermor wrote as follows: 'There seems to be room for a handsome profit in manufacturing ferro-manganese in India,' yet it was not until October 1915, and on account of the increase in its price caused by conditions during the first world war, that its manufacture was commenced by the Tata Iron & Steel Co. Ltd, and in November of the same year by the Bengal Iron Co. Ltd. The production of the alloy in India since that time is summarized below:

PRODUCTION OF FERRO-MANGANESE IN INDIA, 1915-50

PERIOD	TOTAL TONNAGE	PERIOD	TOTAL TONNAGE
1915-18 ..	20,347*	1934-8 ..	49,407
1919-23 ..	16,956	1939-43 ..	78,136†
1924-8 ..	42,338	1944-8 ..	51,405
1929-33 ..	30,633‡	1949-50 ..	31,515§

* After satisfying the needs of the Indian steel industry a balance of 7,555 tons was exported to France, the United States of America, Italy and Natal.

† Production of the Tata Iron & Steel Co. Ltd only.

‡ The year of peak production was 1941 with 31,563 tons.

§ Early in 1955, the Government of India authorized a Bombay firm to erect, with American collaboration, a ferro-manganese plant at Tumsar, to make 30,000 tons annually.

Very large quantities of ferro-manganese are made in other countries; the British consumption alone is at present about 400,000 tons per annum and likely to rise to half a million tons; by 1944 the United States was producing over 700,000 tons per annum, in addition to more than 165,000 tons of spiegeleisen and large amounts of silico-manganese. During the war years Germany made about 90,000 tons of 30 - 60 per cent Mn. ferro-manganese, and 41,000 tons of higher-grade material annually, as well as 408,000 tons of 14 - 30 per cent spiegeleisen, and 240,000 tons of the same alloy with 6 - 14 per cent of manganese, a yearly total of 779,000 tons.

The question is often asked why India does not manufacture ferro-manganese for these and other markets and the answer usually given is that her ores and cokes contain too much phosphorus. To be acceptable to the market, the phosphorus content of ferro-manganese should not exceed 0.1 per cent, although 0.3 per cent is often taken as the maximum limit. By the careful selection of suitable ores, which are obtainable from Madhya Pradesh and elsewhere, and a coke such as that yielded by coal from the Giridih coalfield, with its phosphorus content of 0.022 per cent, this difficulty could doubtless be overcome. After all, Indian iron and steel works make their own requirements by the normal blast-furnace methods, and will continue to do so in the years to come, when the output of the Jamshedpur plant alone is increased from its existing capacity to the 930,000 tons of steel per annum contemplated, when the extensions of the other steel works are in being, and when the projects for the national steel works come to fruition.

In addition to its production in the blast furnace, ferro-manganese is also made on a large scale in electrical arc furnaces, and it may well be that by this process the difficulty mentioned could be completely overcome, though cheap electrical power would be essential.

Standard ferro-manganese contains about 80 per cent of metallic manganese and 5 to 7 per cent of carbon, the balance being mainly made up of iron; standard spiegeleisen contains about 20 per cent of manganese. Ferro-manganese made in the blast furnace may contain from 27 to 86 per cent of manganese and spiegeleisen from 5 to 30 per cent. The products of the electric furnace are richer and may contain up to 95 per cent of manganese. Other ferro-alloys of a similar nature made in the electric furnace are silico-manganese and silico-spiegel. Metallic manganese is used in the manufacture of alloys in which the presence of iron is undesirable, such as the manganese bronzes and certain copper-nickel-manganese alloys. It is also employed as a deoxidizer in non-ferrous metallurgical operations, and is made commercially by reducing its oxides, either by the aluminothermic process or by means of silicon, with or without silico-manganese. An American process depends on the electrolysis of manganese sulphate leached from low-grade ores, and any or all of these products may contain from 97 to over 99 per cent of the metal.

In addition to the quantities used in the production of ferrous alloys, manganese ores are also added to blast furnace charges in Indian iron works. The total amount consumed by the companies concerned for all these purposes up to the end of 1950 was 1,667,367 tons. In recent years this consumption has averaged about 10 per cent of their production—a fraction which it is believed will increase in the future. It may be added here that in addition to the quantities required by the iron and steel works, some 4,000 tons of manganese ores are used annually in India by glass manufacturers and makers of dry batteries.

NICKEL

Nickel occurs in small quantities in the lead-zinc-copper-silver ores of Bawdwin in the Shan States of Burma, and in the course of the smelting operations which were carried on at Nam Tu, until the invasion of Burma by the Japanese in 1942, it was recovered regularly in the form of a speiss. The mineral gersdorffite, a sulpharsenide of nickel, NiAsS , is the principal source of the element, for J. A. Dunn detected it under the microscope in almost every example from a collection of more than sixty specimens of lead-zinc ores from various parts of the great Bawdwin orebody. There are two varieties of gersdorffite, designated as *alpha* and *beta*, and the latter by loss of sulphur can graduate into chloanthite, the diarsenide of nickel, NiAs_2 , which in its turn may graduate into smaltite, the corresponding diarsenide of cobalt, CoAs_2 , by isomorphous intermixture.

Regular returns of speiss production commenced in 1927, and from that time until the end of 1940, 45,457 tons had been made, containing an estimated total of 13,223 tons of nickel, together with

large quantities of cobalt, silver and copper. The speiss was shipped from Burma to Germany for treatment.

AVERAGE ANNUAL PRODUCTION OF NICKEL SPEISS AT NAM TU,
1927-40

PERIOD	TONS	VALUE	COMPOSITION			
			NICKEL	COPPER	COBALT	SILVER
		Rs	%	%	%	oz. per ton
1927-8 ..	1,982	3,55,747	24.72	15.56	*	32.89
1929-33 ..	3,211	8,19,023	27.98	11.64	*	30.06
1934-8 ..	4,032	13,04,918	30.44	9.28	5.85	19.07
1939-40 ..	2,638	12,61,182	30.91	8.23	7.97	14.83

* 3 to 4 per cent cobalt approximately.

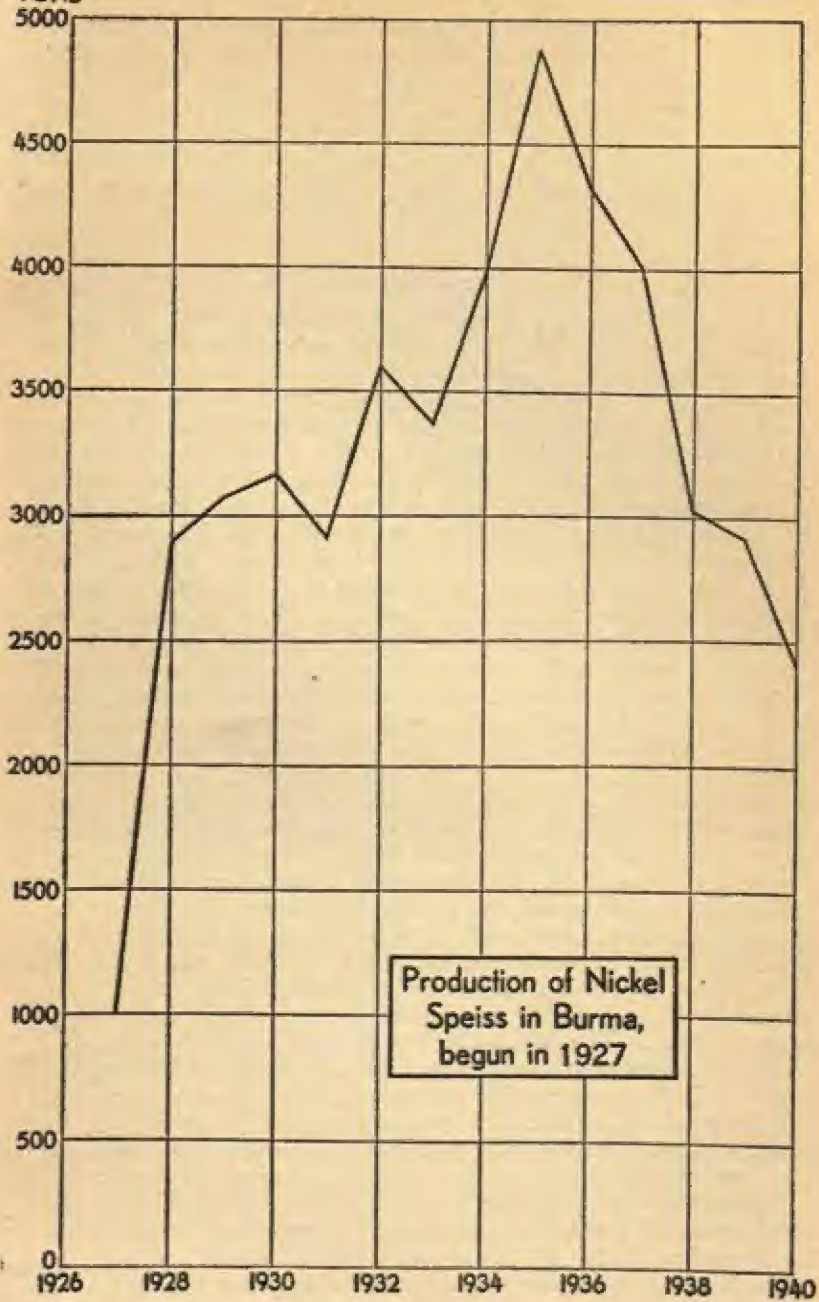
N.B.—According to the Mines Department of the Government of Burma, 3,620 tons of nickel speiss, of unknown composition, were produced in 1951.

Nickel is a constituent of some importance in the copper ores of Singhbhum, Bihar, though the metal has not been recovered from them up to the present time. J. A. Dunn has stated that pyrrhotite, the magnetic sulphide of iron, is perhaps more abundant than chalcopyrite itself in these Singhbhum ores, and that it contains irregular, microscopic patches of both pentlandite and violarite, sulphides of nickel and iron with the formulae $(\text{NiFe})\text{S}$ and $(\text{NiFe})_2\text{S}_4$ respectively. Millerite, the sulphide of nickel, NiS , has also been identified.

Nickel ores are also known to occur in Nepal; thus a vein cropping out at Bhorle, near Nangre, has been traced for 2,500 feet and has been worked by the local inhabitants in places to a depth of about 100 feet. Its average nickel content, according to A. G. Jhingran, is about 2 per cent, present mainly in the form of the diarsenide, chloanthite, NiAs_2 , associated with which are cobaltite, the sulpharsenide of cobalt, CoAsS , traces of zinc and some bismuth compounds.

The presence of both nickel and cobalt in the pyrrhotite of the Khetri deposits of Jaipur, Rajasthan, was proved by F. R. Mallet. The metal also occurs in the mixed sulphide ores (pyrrhotite, pyrite and chalcopyrite) of the Tovala taluk in Travancore; in the sulphides associated with the gold-bearing quartz veins of Kolar, Mysore and as a bloom on the serpentines of Pai Khel in Waziristan, Pakistan. In Kashmir, nickel-bearing minerals have been found at Ramsu, Buniar and Khaleni, as well as in the vicinity of the sapphire mines of Padar. Samples of copper ores from the Riasi *tahsil* contain up to 1.68 per cent of nickel.

TONS



The announcement of the discovery of large deposits of garnierite, a hydrated silicate of magnesium and nickel, in Singhbhum in 1934, has not been confirmed, but S. K. Borooah has described zaraitite, a basic nickel carbonate, $\text{NiCO}_3 \cdot 2\text{Ni(OH)}_2 \cdot 4\text{H}_2\text{O}$, from the chromite deposits of Nuasahi in Keonjhar. It is a green earthy mineral found in the gangue and in the interspaces between the chromite grains themselves. This chromite contains 0.3 per cent of nickel and 0.6 per cent of cobalt.

USES OF NICKEL

In 1948 the world's consumption of nickel, outside the Soviet Union, has been estimated at over 130,000 tons and in 1948 the world's production, allowing 25,000 tons for the Soviet Union, has been given as 149,000 tons though the data are admittedly incomplete. Some 60 per cent of the total consumption is said to be employed in the preparation of nickel alloy steels of various kinds while nickel plating is the second largest field of use, though nowadays generally as an undercoat to chromium. Pure nickel is to be found in the coinage of no less than thirty-six countries, including some of the coins of the Indian Republic. It is also used in the fabrication of vessels to withstand corrosion, either alone or as nickel-clad steel; to build up worn machinery parts by electro-deposition; in radio valves and in depth sounders.

Nickel improves the strength, toughness and hardness of steel, increasing its uniformity, reliability and resistance to fatigue, shock and wear. Taken at one time for the production of armour plate and armaments generally, it was widely regarded solely as a munitions metal until after the first world war; today the low-nickel steels with $\frac{1}{2}$ to 9 per cent of nickel find widespread uses in motor vehicles, locomotives, tractors, excavators, oil-well casings, aircraft and marine engines and indeed in machinery of almost every description. The stainless nickel steels with 2 to 26 per cent of nickel, including the well-known 18/8 variety (see CHROMIUM), possess outstanding corrosion resistance and, finding applications in many industries, are one of the major outlets of the metal. Still higher percentages of nickel and chromium give the heat-resisting steels for furnace parts, mechanical stokers, diesel engine valves and so forth. The nickel-chromium alloys, such as one which contains 80 per cent of nickel and 20 per cent of chromium, have high scaling and electrical resistance, which accounts for their employment as heating elements of electrical furnaces, fires and domestic appliances. The 'Nimonic' alloys of the Mond Nickel Co. are nickel-chromium alloys with small amounts of other elements, which by reason of their resistance to high stresses, high temperatures, gas attack and creep are employed in jet aircraft and similar forms of power production. Their very superior strength at elevated temperatures makes them the strongest of the

materials available for the blading of gas turbines. Another alloy, known as 'Inconel', containing 80 per cent of nickel, 14 per cent of chromium and 6 per cent of iron, finds its chief applications in the food-processing and chemical industries.

Ferro-nickel alloys display wide variations in their magnetic and thermal properties, dependent on their content of nickel. The non-magnetic alloys, with 8 to 27 per cent of nickel, are useful materials for reducing losses in electrical generating plant, transformers and motors. The magnetic alloys, with 35 to 90 per cent of nickel, find their way into telegraph and telephone instruments, submarine cables and radio equipment; others by reason of their predictable behaviour on heating find a place in thermostats, circuit breakers, gas supply controls, overload devices as well as in air speed and altitude indicators. Certain special steels containing nickel, aluminium and cobalt possess twenty-five times the magnetic strength of carbon steel and are employed in loud speakers, small motors, radar instruments, telephone receivers and deaf aids. Nickel steel with 36 per cent of nickel, known as 'Invar', expands and contracts only to a very minute extent with changes of temperature and is used in measuring tapes, chronometers, etc. Another alloy has much the same expansion as glass and can take the place of platinum for 'lead-in' wires.

Nickel improves the strength, toughness and structure of grey cast iron, and such alloys are employed as beds for heavy machinery, cylinder blocks and heads; added to white cast iron, in amounts of 4 or 5 per cent, it imparts high wear-resistance and hardness, conferring at the same time an ability to withstand severe wear and abrasion, such as are met with in components of rock and ore crushers, grinding mills, ball mill linings, brake drums and metal rollers. This alloy is known as 'Ni-hard'. Other alloy irons combine the effects of nickel with those of chromium, molybdenum and other elements and are made to meet special requirements in mechanical engineering.

The nickel-copper alloys include 'Monel metal', which contains about 68 per cent of nickel, 30 per cent of copper with a little iron, and is made directly from its ore without preliminary separation of its two chief ingredients. It resembles silver in appearance, is superior to bronze in durability, equals steel in strength, is amenable to both hot and cold working, resistant to chemical attack, and, consequently, has a very wide range of industrial applications—from house roofs and shop fronts to the parts of aircraft near the compass, for it is non-magnetic; from turbine blades and pump bodies to the canning equipment of food factories; from sinks and soda fountains to pulp and paper mills; from the pots and pans of the kitchen to the evaporators of the chemical factory and the finishing machines in dye works and laundries.

An alloy with 40 per cent nickel and 60 per cent copper has high electrical resistance which changes little with variations of

temperature and accounts for its use in electrical apparatus. Another alloy, with about 30 per cent nickel and a small amount of iron in addition to the remaining copper, is a standard composition for the condenser tubes of naval vessels and large steamships and, indeed, for any other situation subject to the corrosive effects of rapidly moving sea-water carrying air bubbles in suspension. The addition of aluminium to the brass, and of iron to the cupro-nickel alloys formerly used for this purpose, has greatly lengthened the average life of these tubes, increased the steaming capacity of ships and the trustworthiness of their means of propulsion. These and related alloys find outlets in chemical, oil and power plants and are also used in munitions for bullet envelopes.

The 25 per cent nickel-copper alloy is a standard form of coinage in many countries, including India, and in Britain where, since 1946, it has replaced silver. Five per cent of nickel has been added to Indian silver coins since 1940. Other nickel alloys include 'nickel silver', formerly known as 'German silver', a series containing copper, nickel and zinc, with the nickel proportion ranging from about 5 to 30 per cent, and varying the colour from pale yellow to silvery white as the nickel increases. They are made into table-ware and decorative articles of many sorts as well as into flat springs for electrical contacts. 'Silver Plate', or 'E.P.N.S.' as it is often branded, is nickel silver with an electro-deposited coating of pure silver. Nickel is also added to brasses and bronzes to improve their wearing properties; for instance, the Indian brass coinage of 1941 contains 1 per cent of nickel. High-nickel bronzes have their place in steam engineering for valves, pumps, shafts and bearings. The metal is also a component of many complex light alloys to which it gives added strength and hardness, so making them suitable for pistons, connecting rods and cylinder heads of aircraft and automobile engines and for the frames of motor vehicles.

Several salts of nickel are valued catalysts, especially for the conversion of liquid animal and vegetable oils into solid edible fats. Other applications are in the cracking of petroleum, the purification of coal gas, the synthesis of nitrates, ammonia and many organic compounds. The sulphate goes into the solutions of nickel-plating baths; the hydroxide into the positive plates of nickel-iron and nickel-cadmium storage batteries.

This is but a skeleton outline of a most versatile metal which now plays a part in most modern industries.

CONSUMPTION OF NICKEL IN INDIA

Over the years 1934-46 the mints at Bombay, Calcutta and Lahore, the last of which, now in Pakistan, commenced operating in 1943, consumed 1,991 tons of nickel, valued at Rs 88,25,637. As the metal was not available from external sources during the war period, 851 tons of cupro-nickel scrap, valued at Rs 12,99,493,

and containing 20 per cent of nickel and 80 per cent of copper, were obtained from the Indian Ordnance Department for the Bombay mint.

Indian imports of German silver and articles made from it continued to grow until the war slowly strangled the trade. From an annual average of 906 tons, valued at Rs 14,36,362 for the five years ending 1932-3, they had risen to an average of 1,132 tons, valued at Rs 13,26,498, over the five years ending 1937-8. The next decade (1938-9 to 1947-8) started with still greater imports of 1,748 tons in its first year, but thereafter the decline was swift and practically ceased between 1942-3 and 1945-6. This decline was followed by a rapid recovery and the ten-yearly period closed with an annual average of 649 tons and Rs 6,95,012. The marked increase since then, totalling no less than 4,158 tons and Rs 1,93,59,420, for the two years ending 1949-50, may be due in part to the replacement of depleted stocks.

India possesses a source of nickel in the copper ores of Singhbhum, and it is unfortunate that no attempts are made to recover at least part of it to meet the country's demand for the cupro-nickel alloys. It is only fair to the copper smelters to point out, however, that the nickel content of Indian refined copper is said to be advantageous in the particular commercial uses for which it is made. It is true that the ore contains only 0.083 per cent of nickel, taking the only analysis available, which refers to ore won in 1934, but with an annual output of 350,000 tons of ore, this represents 290 tons of nickel every year. Indian refined copper is said to average 0.649 per cent nickel, and to account for only 13 per cent of the nickel originally present in the ore, according to Sir Lewis Fermor, the balance being lost in either the ore concentrating or smelting processes.

Over 90 per cent of the total nickel production of the world outside the Soviet Union is supplied by the nickeliferous sulphide ores of the Sudbury Basin in Ontario, Canada, where the ore reserves in 1949 totalled 236 million tons, containing 3.2 per cent nickel-copper, of which about one half is nickel. The ore deposits are closely associated with a body of norite and micropegmatite, outcropping as an oval ring 37 by 17 miles in diameter and 1 to 3.6 miles broad, and lie along or close to the outer margin of the norite. They consist of rock fragments cemented by the sulphides and partly replaced by them. Similar ores are mined at Petsamo, formerly in Finland but now in the Soviet Union. The nickel ores of New Caledonia are of the silicate type, as are those of the southern Urals, Greece, Brazil, Venezuela and the southern Celebes. Lateritic nickel ores have been mined on a small scale in Cuba.

COBALT

A complex ore of cobalt known as *sehta*, which contains the minerals cobaltite, the sulpharsenide of cobalt, CoAsS, and danaite,

a cobalt-bearing variety of mispickel, the sulpharsenide of iron, FeAsS , occurs with copper and iron pyrites sparsely scattered in irregular strings, layers and lenticles through black slates, without any resemblance to a true lode, in the Babai copper mines of the Khetri area of Jaipur in Rajasthan. The country rock is mostly black slate, siliceous and splintery, with indefinite bands of quartzite of the Ajabgarh Series, in the Delhi System, and is intruded by amphibolites. The mines have been closed as far as copper is concerned for many years, and the extraction of *sehta* ceased about 1908. It used to be recovered by crushing the slate and panning the powder, the heavy concentrate so produced being sold to the Jaipur jewellers for the production of the beautiful blue glazes of their enamel work. Its place is now taken by a more expensive, but better quality, imported product containing cobalt.

Cobaltite is known to occur at several localities in western Nepal, including Tamgas and Samar Bhamar where, judging from the many abandoned pits and adits, now for the most part under water, extensive workings existed in the past. Samples from one adit averaged 5.85 per cent of cobalt. The places mentioned are 5 or 6 days' marches from the nearest railhead at Shohratganj (Sharatgarh). The occurrence of cobaltite with the nickel-bearing ores of Bhorle, in Nepal, is referred to under NICKEL. Linnacite, a sulphide of cobalt, Co_3S_4 , has been recognized in some of the copper ores of Sikkim.

Certain varieties of chromite from the Nausahi area of Keonjhar are reported to contain 0.6 per cent of cobalt and 0.3 per cent of nickel. The presence of both elements has been detected frequently in Indian manganese ores, while mammillary concretions probably best designated as wad, associated with the iron ores of Olatura, near Madanpur, Kalahandi, Orissa, contained 0.82 per cent of cobalt oxide, CoO . According to T. L. Walker, this cobaltiferous wad approaches the New Caledonian and Australian asbolites in composition, and while the sample assayed is not rich enough to be of any commercial value, it would not be surprising if an ore of such variable composition were locally richer than this particular sample, and in that case be rich enough to be worth exploiting.

The presence of cobalt in the mixed lead-zinc sulphide ores of Bawdwin, in the Shan States of Burma, was first noticed by the growth of thin, encrusting layers of pink erythrite on stacks of ore which had been left on the surface exposed to the action of the weather. This mineral, which is also known as cobalt bloom, is the hydrated arsenate of cobalt, $\text{Co}_3\text{As}_2\text{O}_8 \cdot 8\text{H}_2\text{O}$, and an alteration product of the original sulpharsenides of the ore itself. During smelting operations the cobalt finds its way into the nickel speiss, the composition of which is given in the table on p. 222. As the Bawdwin mine was deepened, the cobalt content of the speiss gradually increased from 3 or 4 per cent in the early years (1927-33)

to nearly 8 per cent in 1940, and it is calculated that from 1927, when shipments commenced, until 1940, they contained between 2,270 and 2,370 tons of metallic cobalt.

Cobalt enters into the composition of many ferrous and non-ferrous alloys; thus it is an important addition, in amounts of from 5 to 12 per cent, to high-speed steels based mainly on tungsten or molybdenum, or on both these elements, increasing their cutting efficiency at high temperatures. The permanent magnet steels, already referred to under NICKEL, and known under such names as 'Alnico', contain from 12 to 24 per cent of cobalt, 14 to 32 per cent of nickel, 8 to 12 per cent of aluminium, and, in some cases, 3 to 6 per cent of copper, as well as small additions of titanium, and owing to their very high coercive forces have replaced for many purposes the cobalt steels, which up to the time of their discovery were the best permanent magnet material available. Cobalt steels, apart from their uses in tool and magnet steels, have many other applications in situations where resistance to stresses, oxidation, corrosion at high temperatures and very low coefficients of expansion are needful, and are to be found in razor blades, surgical instruments, die steels, engine valves, glass-to-metal joints and seals, as well as in some parts of jet propulsion machinery. The largest single use of the metal today is in the cobalt-nickel-chromium base alloys required particularly for jet engines.

Cobalt is the chief binding metal or matrix used for cementing the carbide of tungsten, as well as those of molybdenum, titanium and tantalum, the sintered powders of which may contain up to 14 per cent of cobalt. Such materials are the hardest known products of metallurgy, surpassing the hardest steel in this respect and of great industrial utility as tips for many kinds of cutting and abrading tools.

The 'stellites', alloys of cobalt, chromium and tungsten, sometimes modified by the addition of other elements, have been mentioned under CHROMIUM. They may contain from 45 to more than 60 per cent of cobalt and furnish cutting tools superior in some respects to those made from high-speed steel, especially in their performance at elevated temperatures. Such alloys, in the form of welding rods, were in common use on the oilfields of Burma to build up the worn edges of drilling bits: by their means hard-wearing layers can be applied to any machine parts where they may be required.

Cobalt in small quantities increases the hardness and electrical conductivity of the copper-beryllium alloys. It has an important function as a catalyst in the Fischer-Tropsch process for the synthesis of liquid hydrocarbons from carbon-monoxide and hydrogen mixtures; the material used in the German plants during the last war for this purpose is stated to have consisted of cobalt 100, thoria 5, magnesia 8, and kieselguhr 200 parts. The metal has also been used as a catalytic desulphurizer of crude petroleum.

The ceramic industry absorbs much of the cobalt oxide of commerce to give the blue glazes of pottery and earthenware; glass and enamel makers also use it for similar purposes. Cobalt salts are, on the other hand, employed as decolorizing agents in potteries to counteract the slight yellow tinge caused by traces of iron compounds when most clays are fired, the complementary blue coloration neutralizing the yellow one, and yielding a pure white product. In the vitreous enamelling of iron and steel, small additions of cobalt oxide to the frits promote the adherence of the coatings to the metal bodies. Soluble cobalt compounds are added to nickel-plating baths to produce hard, smooth and bright surfaces on the finished articles, and so to lessen or eliminate later costly polishing operations. Certain organic compounds, such as the resinate and oleate of cobalt, are active driers of oils and superior in this respect to compounds of iron and manganese: by their use a number of semi-drying oils can be employed in the manufacture of paint in place of the more expensive linseed oil. They have further uses in the manufacture of waterproof textiles, printing inks, linoleum and other products. Other cobalt salts are employed in veterinary medicine and in the form of soil dressings on grazing lands as a preventive of deficiency diseases amongst sheep. The radioactive isotope known as cobalt 60, a product of the atomic pile, emits gamma rays of much the same energy as those from radium. It has a half-life of 5.3 years and is a substitute for radium both in therapeutics and in industrial radiography.

Thirty years ago the world's annual consumption of cobalt was about 750 tons; by 1939 it had reached 4,000 tons and in 1948 the estimated output of the producing countries, still expressed in terms of metallic cobalt, was about 5,900 tons. Practically the whole of this is obtained, just as it was in Burma, as a by-product from complex ores primarily smelted for other metals and principally for copper; thus the copper deposits of Katanga, in the Belgian Congo, and those of Northern Rhodesia, between them accounted for over 78 per cent of the total in 1948. If the copper ore deposits of Rajasthan, or of the Outer Himalayan belt in Sikkim, Nepal and elsewhere, eventually come to be worked on a large scale, it is likely that India will enter the list of cobalt-producing countries.

CHAPTER V

THE STEEL-HARDENING METALS

CHROMIUM

CHROMITE, the ore of chromium, has the ideal composition FeCr_2O_4 or $\text{FeO} \cdot \text{Cr}_2\text{O}_3$, corresponding to 68 per cent of chromic oxide, but as part of its iron is often replaced by magnesium and some of its chromium by aluminium, the commercial ore seldom contains more than 50 per cent of chromic oxide, Cr_2O_3 .

The mineral was first mined in Baluchistan in 1903, in Mysore in 1907 and in Singhbhum in 1909. It was not until 1937 that Seraikela of the Eastern States Agency, now part of Bihar, began to deliver chromite, to be followed by Keonjhar, now in Orissa, in 1943. The Krishna district of Andhra has made small contributions since 1941, and sample parcels have also been taken from Salem in Madras and from Ratnagiri in Bombay.

The Baluchistan ores, discovered by E. Vredenburg in 1901, occur sporadically as veins and irregular, magmatic segregations in serpentines formed by the alteration of saxonites (enstatite peridotites) of Cretaceous age. The chief mines are near Hindubagh, in the Zhob Valley, but production was extended to the adjoining Quetta-Pishin district in 1937. Similar intrusive, ultrabasic rocks have been found in Waziristan further to the north-east, and in Kalat to the south and certainly merit prospecting for chromite. The Baluchistan ore is of exceptional quality and as exported from Karachi often averages over 53 per cent chromic oxide.

Over 40 per cent of the grand total of India's chromite production has been mined or quarried from the Mysore and Hassan districts of Mysore, where the mineral was discovered by H. Slater in 1898. Veins, lenses and segregations of chromite, often associated with magnesite, occur in serpentinized ultrabasic rocks between Mysore City and Nanjangud, and have been exploited at a number of localities. The Sinduvalli mine of Mysore Chromite Ltd reached a depth of 600 feet and gave over 136,000 tons of high-grade ore, averaging 50 per cent chromic oxide, before becoming exhausted. Smaller deposits at Talur, Uradabur and Dodkatur yield low-grade ore (40 to 44 per cent Cr_2O_3), while several others which are not mined average about 30 per cent. Further low-grade deposits are known in the Chikmagalur, Shimoga and Chitaldrug districts. At Pensamudra, about three miles from Arsikere in the Hassan district, low-grade ores are mined and concentrated by

Mysore Chromite Ltd for the manufacture of sodium dichromate at Mysore, Bombay and Kanpur. There are many orebodies in this area, lenses and veins in talc-serpentine rocks, themselves altered enstatite-peridotites of the Nuggihalli schist belt which stretches for 35 miles from Jambur to Arsikere. They are mainly of low-grade quality but at Byrapur massive and friable high-grade ores are found, averaging 48 to 50 per cent chromic oxide. Worked extensively in the past for export, these are now reserved for ferrochrome manufacture at the Mysore Iron and Steel Works, and such small quantities as are removed at present supply refractory materials for use in these works. Mysore chromite in general, as exported from Marmagao in the past, contained from 40 to 48 per cent of chromic oxide.

The chromite deposits of Singhbhum, found by R. Saubolle in 1907, lie near Jojohatu, west of Chaibasa, in partly serpentinized saxonites, dunites and pyroxenites. Their lenticular veins, up to 3 feet in width and 100 feet in length, are not large, but they form a persistent ore-bearing horizon capable of yielding 4,000 to 5,000 tons of 50 per cent ore per annum for many years to come, according to Dr J. A. Dunn. Adjoining Singhbhum, the former state of Seraikela (now in Bihar) yielded a few hundred tons of low-grade chromite from the usual, highly altered, ultrabasic intrusive rocks, between 1937 and 1942.

In Orissa, large orebodies were discovered on the Baula Hills in Keonjhar in 1943. Here, lenticular, steeply dipping, echeloned lenses of ore, primary differentiates of an ultrabasic magma, have been intruded in successive stages so that several generations of chromite are recognizable; a coarse-grained early one, preceding a medium-grained intermediate stage, and a final fine-grained phase, both of which cut through the coarse ore in places. The massive hand-cobbed ore, as marketed, averages 52.4 per cent chromic oxide, according to S. K. Borooah, and thus compares favourably with Baluchistan chromite. The probable reserves to a depth of 50 feet are of the order of 200,000 tons, and up to February 1949 approximately 50,000 tons had been won. Further finds of chromite have been reported from localities close to Nausahi as well as from the adjoining Sukinda Estate, in the Cuttack district of Orissa. The chromite in Sukinda occurs along a quartzite-peridotite junction and as small patches in lateritized dunite. To the west, in Dhenkanal district, rich deposits capable of yielding at least 120,000 tons have been found along shear zones in peridotite south of Maruabil. The mineral also occurs in quartzite near Ghotringa, 12 miles north-west of Maruabil, and near Khantalsuan 10 miles further north-west.

About 11 miles south of Tiruchengodu, in the Salem district of Madras, chromite is associated with other minerals in parallel bands which have been traced for a distance of 12 miles in the local anorthite gneiss. By magnetic methods alone, concentrates can

be obtained from these ores containing up to 40 per cent of chromic oxide and it is possible that they may prove useful for refractory purposes.

The chromite deposits of Kondapalle, Krishna district, Andhra, are in the form of lenses and pockets in partly serpentinized pyroxenites interbedded with charnockites, and their exploitation has assumed some importance since 1948, but they appear to be pinching out in depth. Low-grade deposits occur in serpentine near Kankanli, in Ratnagiri, and Vagda, in Savantwadi, Bombay. The mineral has been found at many other places in India, Pakistan and Burma and only those larger deposits of actual or potential commercial importance at the time of writing can be mentioned here. Others certainly remain to be located, particularly in regions containing many outcrops of ultrabasic rocks such as Manipur and the Arakan Yoma.

The lustrous, silvery-looking, coating of chromium now plated on so many articles to protect them from rust and wear is familiar everywhere, but this use accounts only for insignificant amounts of chromite. Today, probably more than half of the world's production of some 1·5 million tons (excluding the Soviet Union) is consumed by the metallurgical industry, perhaps about 40 per cent for refractories and the remainder for chemical manufactures.

Chromium is the most widely used of all the steel-alloying elements because of its ability to impart additional strength, hardness and resistance to corrosion. By varying the quantity of chromium, by the addition of other elements with it, particularly nickel, tungsten, molybdenum, vanadium and manganese, and by suitable heat treatments, a bewildering variety of different steels are made, each with its distinctive properties and special applications. They range from the low-chromium steels with from 0·5 per cent to 4 or 5 per cent of the metal on the one hand, to alloys with little or no iron at all on the other. In the former group, often containing nickel and other elements as well, are some steels very widely used by the mechanical engineer, particularly for gears, ball and roller bearings, shafts, axles and connecting rods in all kinds of civil and military vehicles, in locomotives, tractors and excavators, as well as in armour-plate, projectiles and machinery subject to rough usage. In the latter group are the nickel-chromium alloys of the 80/20 class—the heating elements of electrical furnaces, fires and domestic appliances. Similar alloys are to be found in the vital parts of jet engines as they withstand high stresses, elevated temperatures, the attack of hot gases and are resistant to creep.

Between these extremes are many other important groups including the 'stainless' steels, with 12 per cent to 20 per cent of chromium; the 'rustless' irons with 2 per cent to 5 per cent of chromium; the high-speed tool steels with about 4 per cent of chromium; the corrosion-resisting steels of the 18 per cent chromium

and 8 per cent nickel type, and the heat-resisting steels with somewhat higher percentages of the same metals, extensively employed for furnace parts, diesel engine valves and so forth.

Other important chromium alloys include 'Inconel' with 80 per cent nickel, 14 per cent chromium and 6 per cent iron, a favourite material for the manufacture of food-processing equipment, and the 'Stellites' with 20 to 35 per cent of chromium, 50 to 65 per cent of cobalt, tungsten and other elements—extremely hard substances used for machine tools, abrasive facings, rock drills, etc. Metallic chromium, of 99.0 to 99.5 per cent purity, is made on a large scale by the aluminothermic reduction of chromic oxide, itself prepared from sodium dichromate, a product obtained by roasting chromite with sodium carbonate and limestone. For many purposes, the alloy ferrochromium with 60 to 70 per cent of chromium, made by reducing chromite with carbon in the electric furnace, is used. High and low carbon varieties are marketed, the latter containing from 0.03 to 0.15 per cent carbon.

Chromite is an essential mineral for the iron and steel industry, and after being turned into bricks, shapes, plasters and cements is utilized in the construction and repair of steel furnaces. These uses are more fully discussed under REFRACTORIES.

The chromates and dichromates of sodium and potassium, together with many other salts of the element such as chrome alum and chromium sulphate, are important industrial chemicals, particularly in the tanning and dyeing trades. Indian annual imports of the dichromates before 1939 were of the order of 1,000 tons per annum, but the war demand increased to some 6,000 tons per annum and led to the development of their manufacture in the country, so that by 1946, 13 factories with a total capacity of 5,075 tons per annum were in existence. The chromate of lead furnishes several yellow pigments for the paint-maker; mixed with Prussian blue it yields various green pigments. The basic lead chromate supplies the chrome reds. The chromates of zinc and barium, like those of lead, are also employed extensively for colouring paints, linoleum, rubber and ceramics. Chromic oxide, besides being a source of the pure metal, is a valuable green pigment, as are a number of hydrated oxides, obtainable in commerce under various names. Chromic acid solutions are used in chromium plating, in the anodizing of aluminium and in the protection of magnesium base alloys. Chromium plating is not entirely a matter of producing a durable and decorative finish on articles in common use; thicker coatings are sometimes employed to resize machine parts, to increase the wear-resistance on tools and to line pump rods, engine cylinders and machine-gun barrels. Chromium salts are also used in photography, in the manufacture of safety matches, in the bleaching of oils and fats, in some types of electrical batteries and as catalysts in the preparation of aviation petrol and methanol, an industrial alcohol.

From the commencement of chromite mining in 1903, up to the end of 1946, a grand total of 1,409,423 tons, of a reported value of Rs 2,27,56,593, had been produced. Of this amount 672,117 tons, or 47·6 per cent, were from Baluchistan; 575,325 tons, or 40·9 per cent, were from the Hassan and Mysore districts of Mysore; 139,109 tons, or 9·8 per cent, were from Singhbhum; 20,403 tons, or 1·4 per cent, from the Eastern States Agency (now parts of Orissa, Bihar, Madhya Pradesh, etc.), and the remainder from the Krishna district of Andhra and from Bombay. Over the 44 years involved India contributed 52·4 per cent and Pakistan 47·6 per cent to the grand total. For the five years ending 1946, the average annual tonnages were 24,071, valued at Rs 3,60,476, for Baluchistan; 6,581 tons, valued at Rs 1,85,430, for Mysore and 4,696 tons, valued at Rs 1,75,935, for Singhbhum. It is not surprising that output reached its record of 62,307 tons in 1937, for chromite ranks high in the list of minerals of strategic importance.

Since the separation of Pakistan in 1947, India has won a further 93,417 tons of chromite, valued at Rs 28,98,003, in the years 1947 to 1950 inclusive: of this quantity 39·8 per cent came from the Hassan and Mysore districts of Mysore, 36·7 per cent from Keonjhar, in Orissa, while the remainder was nearly equally divided between the Krishna district of Andhra with 11·8 per cent and Singhbhum with 11·7 per cent. In Pakistan during the same three years 72,404 tons were raised.

Only about 5,000 tons of the chromite mined annually in India used to remain in the country, the remainder being exported, though in 1949, export quotas were introduced to control this overseas trade. In the pre-war period 1934-8, Norway received most of India's chromite, followed by Germany, with the United Kingdom a close third. Norway with her abundant supplies of hydro-electric power doubtless used the ore for the production of high-grade ferro-chrome for sale to the steel-making countries.

The chief producing countries are the Soviet Union, Southern Rhodesia, Turkey, the Union of South Africa, New Caledonia, Cuba, Yugoslavia and Greece, and it is very noteworthy that all the major steel-making countries of the world are dependent on imported ores. In the pre-war quinquennium, the world's average annual production was approximately one million tons, to which India contributed 4·5 per cent and occupied the eighth position on the list.

India and Pakistan between them possess sufficient chromite reserves of the varying grades required by the consuming industries and will doubtless develop the manufacture of more finished products in all three branches—metallurgical, refractory and chemical—in due course. Earlier experiments in the manufacture of ferro-chrome at Bangalore and Bhadravati were unfortunately abandoned in 1932, but during the last war the ordnance factories made their own requirements. As the Indian steel industry grows and the

present output of special steels expands, the internal demand for chrome ores of both metallurgical and refractory grades will increase, and the country is fortunate in that, unlike most other large steel-producing countries, it has at hand more chromite than it needs. Chromite bricks and other chrome refractories are made at present by the Tata Iron and Steel Company and by Messrs Burn and Company, in sufficient quantities to satisfy home needs. The solution of the question of an external market for Indian-made high-grade low-carbon ferro-chrome rests almost entirely on the cost of electrical power. Without cheap power, a quality alloy of the type envisaged could not compete successfully with the existing European and American brands in foreign markets.

Finally, the pioneer work of P. I. A. Narayanan on the beneficiation of chromite ores should lead to the profitable working of lean ores, unmarketable in normal times. This is perhaps the most serious problem facing the chromite mining industry in India.

NIOBIUM (COLUMBIUM) AND TANTALUM

Columbite and tantalite, the niobate and tantalate of iron and manganese, respectively, $(\text{FeMn})\text{Nb}_2\text{O}_6$ and $(\text{FeMn})\text{Ta}_2\text{O}_6$, are hard, black, massive or orthorhombic minerals which pass by insensible gradations from normal columbite, the nearly pure niobate, at one end of an isomorphous series, to normal tantalite, the almost pure tantalate at the other; theoretically, the pure niobate of iron contains 82.7 per cent of niobium pentoxide (Nb_2O_5) and the corresponding tantalate 86.1 per cent of tantalum pentoxide (Ta_2O_5). As niobium is only about half the weight of tantalum, the specific gravity of the mineral changes with its chemical composition, becoming greater as the tantalum percentage increases, and ranging from 5.1 in columbite up to almost 8.0 in tantalite, thus affording a rough-and-ready means of determining quickly to which end of the series any particular specimen belongs. As a general rule, Indian ores are richer in niobium but some varieties with over 30 per cent of tantalum pentoxide have been sold as tantalum ores. The twin minerals have now been identified from over twenty localities in India, ranging from Mysore in the south to Kashmir in the north, of which only a selection can be referred to here.

Their earliest mention is in the Report of the Madras Museum for 1855, ferro-tantalite, an old name for tantalite, having been identified by E. Balfour from a specimen collected at Palni, in Madurai district. In 1894, Sir Thomas Holland found both columbite and tantalite in a pegmatite on Pananoa Hill, in the Monghyr district of Bihar, while about 1900 B. Jayaram reported its presence in a pegmatite near Masti, Bangalore district, Mysore. Crystals of columbite up to 14 lb. in weight, arranged in fan-like aggregates in the feldspar of pegmatite intruded into garnetiferous

mica schists near Pichhli, Gaya district, Bihar, were described by G. H. Tipper in 1919. Similar occurrences to these are known in other pegmatites in various parts of Bihar and Mysore, as well as in the Nellore district of Andhra and Tiruchirapalli district of Madras.

In 1943, J. K. Soneji found columbite-tantalite crystals in his mica mine at Ugai, Kekri *tahsil*, Ajmer-Merwara; later W. N. Khan reported the same mineral in appreciable quantities in Mewar, where it was mined at Lakola, Soniana and Sangua in 1943, together with beryl from the same pegmatites. There are further occurrences in the Lohagal-Makewali area, at Qazipura, west of the Ajmer reservoir, and at Bir, eight miles south of Ajmer. In the parent pegmatites of Rajasthan the minerals are usually associated with pink or white albite, often of the cleavelandite variety, greenish mica, quartz and beryl. H. Crookshank, with a wide experience of these rocks, believes that columbite is commonly present wherever beryl is found, but on account of its general outward resemblance to the relatively valueless ilmenite, which with magnetite is distributed sparingly in a great many pegmatites, it has escaped the notice of the beryl miners. It is to be looked for in the intergrowths of quartz-feldspar and small beryls, rather than with the large beryl crystals of the pegmatite cores.

Small parcels of 112 lb. and 100 lb. of columbite were won in Mysore in 1913 and in the Monghyr district of Bihar, respectively. The mines in Merwar yielded a total of 6,660 lb. in 1943, of which 1,555 lb. came from Sangua and the remainder from Lakola and Soniana. The ore from Sangua averaged 13.8 per cent Ta_2O_5 and 61.7 per cent Nb_2O_5 ; the Soniana ore 39.4 per cent Ta_2O_5 and 41.4 per cent Nb_2O_5 ; the Lakola ore 30.5 per cent Ta_2O_5 and 45.5 per cent Nb_2O_5 . As the official statistics issued by the United States Bureau of Mines reveal that 21,600 lb. of niobium ore and 1,805 lb. of tantalum ore were imported from India into that country in 1943, it is evident that the Indian statistics are incomplete. Such as they are they show a further output of 1,019 lb. of columbite-tantalite in 1944. There can be little doubt that appreciable quantities could be obtained in Merwar provided prices were sufficiently attractive.

Other Indian minerals containing niobium and tantalum are samarskite, a niobate and tantalate of yttrium, and the cerium group of elements, uranium, iron and calcium, from Sankara, Nellore district, Andhra; sipylite, a niobate and tantalate of the rare earth elements and uranium, from Sankara and Razulapad, in Nellore; hatchettolite or endolite, the former being a variety of pyrochlore with uranium and the latter probably an altered pyrochlore, itself a niobate and titanate of the cerium elements and other bases with thorium, from Vayampati, Kadavur (Tiruchirapalli); aeschynite, a niobate and titanate of the cerium elements with thorium, and often containing uranium in addition, and

euxenite, a niobate, tantalate and titanate of yttrium, cerium and uranium from the Erania taluk of Travancore. Other complex niobates, tantalates and titanates of the rare earth elements such as fergusonite, the niobate and tantalate of yttrium, and annerodite, the niobate of uranium and yttrium, occur in Ceylon, and as more or less similar geological conditions prevail in the adjacent parts of southern India, intensive prospecting would probably reveal them there too. They are all of pegmatitic origin and of more potential value for their uranium content than as ores of niobium or tantalum.

Tantalum is marketed in the form of powder, ingots, wire and strip, and by reason of its mechanical strength, hardness, ready workability, high melting point and resistance to corrosion by most chemicals, has many uses. Niobium (known as 'columbium' in the United States of America) has similar properties, and mixed alloys termed 'ferro-columbium' in commerce, which in reality contain all three metals, are made directly from columbite by the aluminothermic process.

Tantalum is employed in the manufacture of large high-vacuum valves for radio broadcasting and reception, for it has the additional property of absorbing gases when heated; its inertness renders it suitable for chemical works equipment, especially in acid absorption plants, valves and nozzles for water chlorination, linings for steel and copper pipes and so forth. It is employed in spinnerets for rayon fibres, in electrical rectifiers, in fountain-pen nibs and in surgical and dental instruments. It does not irritate living tissue and is used in plates for skull injuries as well as in pins, wires and screws in osteological operations. Tantalum carbide is one of the hardest substances known and is incorporated with tungsten carbide in tips for machine tools. The metal has been substituted for platinum for some purposes and its oxide enters into the formulae of some types of glasses for aircraft camera lenses.

The metal niobium has assumed importance as a fractional addition to steels of the stainless types in which it acts as a carbide stabilizer, prevents intergranular corrosion and increases resistance to excessive heat. 'It is therefore a vital constituent of heat-resisting steels for gas turbines and jet engines and an essential addition to electrodes for welding certain stainless steels,' writes Sir Charles Goodeve of the British Iron and Steel Research Association, adding that niobium is also a constituent of recently-developed permanent magnet alloys. 'Alternatives—such as titanium or tungsten—may be used for some purposes, but the demand for niobium, particularly for heat-resisting steels in gas turbines will most probably increase.'

Over the three years 1937-9 about 500 tons of columbite and 150 tons of tantalite were produced in the world as a whole. In 1948, the total combined production of both minerals was 1,773 tons, of which at least 1,100 tons were of columbite and the remain-

der mainly tantalite-columbite concentrates. Nigeria produces over 85 per cent of the world's columbite, mainly from gravels in which it is associated with cassiterite. It is a by-product of the Nigerian tin mines, and the bulk of the output (over 2,000 tons in 1944) has come from the re-treatment of old dumps. The exported ore averages 65 per cent Nb_2O_5 and 5 per cent Ta_2O_5 and nearly all of it is shipped to the United States of America. The Belgian Congo follows in the second place, with 143 tons of tantalite-columbite concentrates and 513 tons of mixed cassiterite-tantalite-columbite concentrates in 1948. Australia was for long the largest producer of tantalite but little is mined there at present. Other countries such as Brazil and South Rhodesia have given appreciable quantities in times of emergency. The high outputs from Nigeria cannot continue for long unless new deposits are found, while the increasing demand for niobium should mean stable markets and good prices for columbite in the future. It is in the light of these circumstances that the development of India's resources of these scarce and valuable minerals should be viewed.

MOLYBDENUM

Molybdenite, the sulphide of molybdenum, MoS_2 , contains 60 per cent of the metal and is a lustrous, lead-grey mineral usually found in small scales which, owing to its perfect basal cleavage, can be split into thin leaves by the finger-nail. It resembles some forms of graphite extremely closely and has probably often been overlooked by prospectors in Eastern lands on this account. It has been found at many places in India, including parts of Chota Nagpur and chiefly in the Hazaribagh district, as, for example, with the sulphides of lead, copper and zinc near Mahabagh, at Baragunda, and elsewhere. It occurs in a granite-gneiss at Cherrapunji, in the Khasi Hills of Assam, in pegmatite veins at Kumavaram and other places in the Godavari district of Andhra; under similar conditions near Karadikuttam and Kodaikanal Road station, in the Madurai district of Madras; associated with pyrrhotite at Mangamalai, Travancore and in the elaeolite syenites of Kishengarh, Rajasthan.

In Burma it is a constituent of some of the wolfram and cassiterite-bearing veins of the Indo-Malayan mountain ranges, as at Mekontaung in Yamethin, and Shwegyaung in Mong Pai, as well as at various localities in Tavoy and Mergui. At the wolfram mines of Sonsinpaya, Wagon North, Thingandon, Hermyingyi and Widnes in the Tavoy district, it is more abundant than elsewhere. An unusually large quartz vein in the Shinmataung section of the Widnes mine, 6 to 8 feet in width, contains a little wolfram, some pyrite and relatively large amounts of molybdenite. The mineral is also a rare accessory of the local granite but is commoner in pegmatites and greisens, in veins with wolfram or cassiterite, or

both, or, again and very much more rarely, in quartz veins in which it is the sole metallic mineral, or perhaps accompanied with a little pyrite. It is found more frequently in veins traversing granite than in those penetrating sedimentary rocks, and it usually lies close to the walls, intergrown with the mica often present in such positions. Small specimen parcels of molybdenite have been shipped from Lower Burma from time to time, but the total output has been quite insignificant. As a result of primitive mining methods and the absence of suitable milling and concentrating machinery, these deposits have never received the attention which they deserve.

Molybdenum is prepared by the reduction of its oxide with hydrogen and is a silvery white metal with the high melting point of 2620°C . In the form of wire, rod and sheet it is widely employed in the manufacture of incandescent electric lamps, particularly as filament supports, and in wireless valves and electronic devices of many kinds; thus the heaters of radio receiving and transmitting valves may be of molybdenum-tungsten alloy. Other applications of the metal include contact points, electrodes, spot welder tips, thermo-couples and heating elements of electric furnaces. Its principal use, however, is in the steel industry as an alloying element, for added to steel in the form of ferro-molybdenum, molybdenum trioxide or calcium molybdate, in amounts usually ranging from under 1.0 to 1.5 per cent, it imparts strength, elasticity, resistance to shock and fatigue, and so enhances the effects of other additions such as nickel, chromium and vanadium. Such alloy steels have their special applications not only in structural materials but also in aircraft and motor vehicle engines, the reciprocating parts of locomotives, drilling machinery and so forth, besides being used for certain types of armour plate and projectiles. Molybdenum-bearing cast irons too, are tougher, stronger and more easily machined by reason of its addition. It is an important component of high-speed self-tempering machine tools used for cutting steels, and during the last war, owing to the scarcity of tungsten, molybdenum was widely employed as a substitute. With chromium and cobalt it enters into the composition of some varieties of the non-ferrous 'stellite' alloys which are also employed as cutting tools.

A number of molybdenum compounds find applications in the chemical and ceramic industries. Ammonium molybdate is the standard reagent for the analytical determination of phosphorus. In passing, it is to be noted that the rare element rhenium occurs chiefly in molybdenite ores.

The average annual world's production of molybdenum for the period 1934-8 was approximately 10,000 tons of which the United States supplied about 90 per cent, mostly from a single deposit at Climax, Colorado, where the grade averages about 0.5 per cent of the sulphide. In 1947 the world's total was over 21,500 tons,

of which 93 per cent came from the United States with smaller amounts from Canada, Finland, Norway, Mexico and Chile.

TITANIUM

Ilmenite, a titanate of iron, FeTiO_3 , with 31.6 per cent of titanium, is often referred to in the older Indian geological literature as titaniferous iron sand, titaniferous iron ore, titanoferrite, meccanite and iserine. It can be found in the concentrates of the sands of most Indian rivers traversing crystalline rocks, but the black sands of the Travancore coast are its sources of greatest importance. Here it is derived from the gneisses and associated pegmatites which build up most of southern Travancore, whence, with quartz, garnet, monazite, zircon, arizonite, sillimanite and rutile, it is carried by the rivers to the sea shore and concentrated into certain patches of sand lying along the beaches between Nindikarai, north of Quilon, on the west coast, to Cape Comorin and thence up the east coast to Lipurum, in Tirunelveli district, a distance of about 100 miles. Smaller patches of similar sands are also known on the beaches of Malabar, Ramanathapuram, Tanjore, Visakhapatnam and Ganjam and are being worked also at Malgund, north of Ratnagiri, Bombay. India's reserves of ilmenite in this form alone total between 300 and 350 millions of tons.

The Travancore sands are exploited at Manavalakurichi near Kolachel and at Kovilthattam, 8 miles north of Quilon, and, as won, contain 50 to 70 per cent of ilmenite, averaging about 55 per cent of titania (titanium dioxide, TiO_2), with monazite, zircon, garnet, rutile and sillimanite as by-products. Rutile, the natural dioxide, with 60 per cent of titanium, which forms from 1 to 4 per cent of the sand grains and some 2 per cent of similar deposits in Ceylon, has a much higher market value than ilmenite, owing to its special uses, higher metallic content and greater scarcity. It is recovered from the zircon fraction of the sand, in which it forms about 12 per cent of the total. Rutile is plentiful in the kyanite-bearing rocks of Lapsa Buru in Singhbhum, but has not yet been recovered commercially. Arizonite, which remains with the ilmenite, is another titanate of iron, $\text{Fe}_2\text{O}_3 \cdot 3\text{TiO}_2$, with about 36 per cent of titanium.

Titanium-bearing magnetites occur in Singhbhum, Mayurbhanj, the Channapatna area of Mysore, and other places. Vanadiferous ores of this type described by J. A. Dunn and A. K. Dey from Singhbhum, for example, average 17.47 per cent of titania. Although various processes have been devised in some countries to produce pig iron and slags, usable as a source of titanium compounds, from such materials, the necessity does not arise in India with its vast resources of more tractable iron ores and of ilmenite.

A further potential large-scale source of titanium exists in Indian laterites and bauxites, the latter often containing upwards

of 8 per cent titania, and forming a useful by-product of the aluminium industry of the future. Methods for its recovery have already been proposed by a number of Indian chemists.

Titanium is a silvery-white, light metal with a density of 4.5 (compared with 2.7 for aluminium and 7.8 for iron) and a melting point of 1795° C., compared with 1537° C. for iron. It is strong, hard and tough with great resistance to corrosion, combining, it is said, the properties of stainless steel with those of the strong aluminium alloys, and is now obtainable in limited quantities in a wide range of fabricated products. It is made commercially by various methods, including the reduction of its tetrachloride with magnesium, but its high cost of production severely restricts its use at present. When improved and cheaper methods of production have been invented, its applications in structural and mechanical engineering will expand rapidly. It is reported that a contract was signed on 10 August 1953 between the British Ministry of Materials and Imperial Chemical Industries Ltd under which this firm is to construct the first full-scale plant for the manufacture of metallic titanium in Britain and that production is to commence in 1955.

Ferro-titanium, used at one time to deoxidize steel made by the Bessemer process, is now employed to introduce titanium into foundry irons and into steels of miscellaneous types, particularly into the chromium-nickel, heat-resisting and stainless varieties, as well as for cleansing purposes into steels that are to be rolled into galvanized sheets or tinplates, or made into enamelled ware or stamped articles. By reason of one or other of its properties as a gas-removing, grain-refining, age-hardening or strengthening element, titanium is to be found in a number of nickel, nickel-cobalt and aluminium alloys, as well as in those used for the manufacture of permanent magnets.

Titanium carbide is extremely hard and is incorporated with the carbides of tungsten and other metals in tools for cutting steel, in dies and in abrasive wheels. The electric welding of steel, which has superseded riveting in many processes, necessitates the employment of rods coated with rutile or titanium dioxide to stabilize the arc and to improve fluxing.

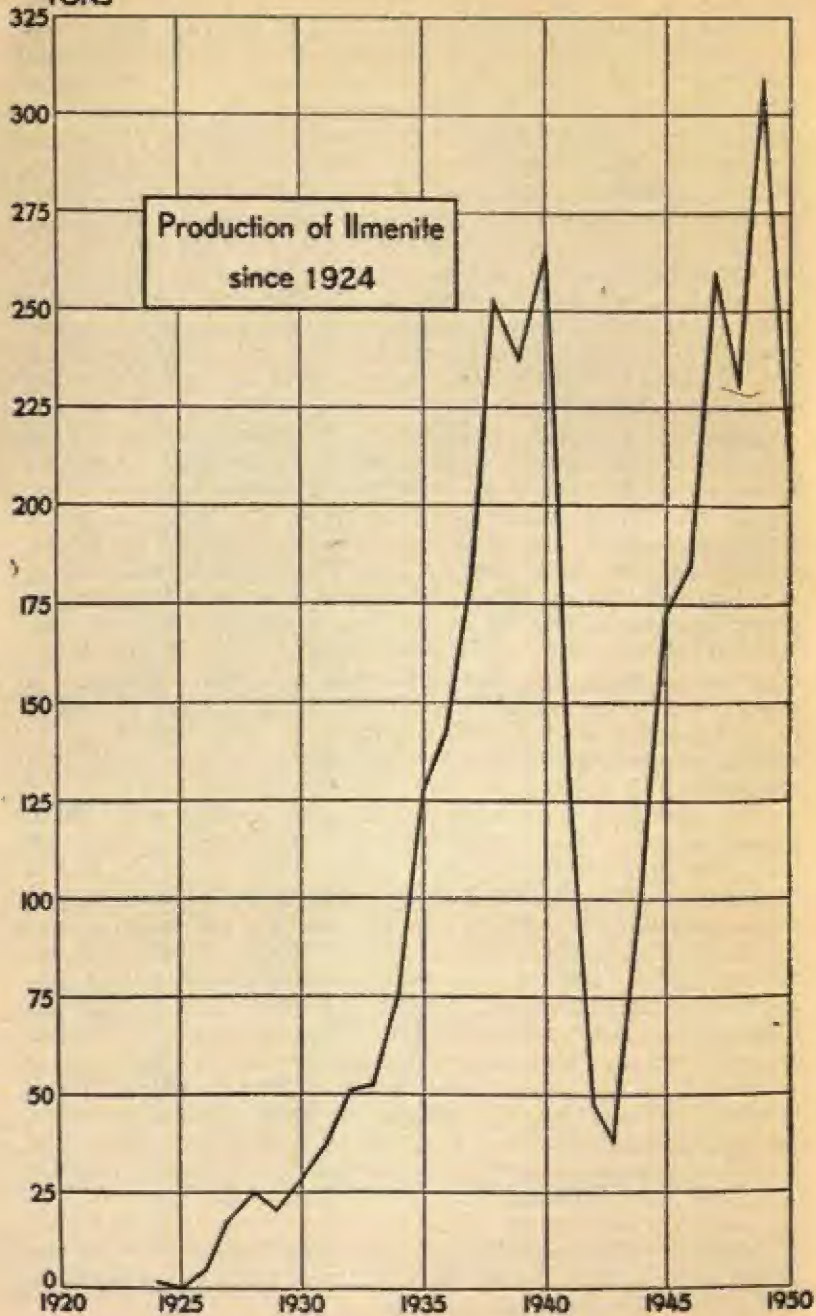
Titanium compounds are employed in the manufacture of vitreous enamels for steel and cast-iron goods, in the production of honey-yellow underglazes for porcelain and in the ivory finish of artificial teeth. Titanium dioxide, either alone in amounts of 8 to 12 per cent, or with the addition of zinc oxide, produces the pleasing 'crystal' glazes of porcelain. Other titanium salts have their applications in glass-making, while rutile and the magnesium orthotitanates derived from it enter into the composition of electric condensers because of their high dielectric constants; further, the titanates of barium and strontium are the predominating components of the ultra-high insulating ceramics.

Certain titanium salts are used as catalytic agents. Both titanium chloride and sulphate possess strong colour-reducing properties and are employed as stripping agents for wool, cotton, viscose and acetate textiles as well as for decolorizing paper, removing iron stains and bleaching discoloured whites in laundering; in sugar refining; in textile printing; for the removal of iron from sand to be used for making optical glass and as analytical reagents. Titanium phospho-oxalate and titanium potassium oxalate are fixing agents in the dyeing and staining of leather, and themselves yield fast, yellowish-brown shades on vegetable tanned leathers. The tetrachloride, a straw-coloured liquid, furnishes range-finding devices and obscuring smoke screens for land and sea operations in warfare, as well as the substance of 'sky-writing' by aircraft in times of peace. Artificial rutile, a product of the electric furnace, is cut into synthetic gems.

Most of the world's production of ilmenite, however, is consumed in the manufacture of the titanium dioxide pigments, which by reason of their opacity, covering power, chemical inertness, low specific gravity, non-toxicity and cheapness are employed on an increasing scale in white paints, enamels and lacquers for indoor use. 'Titanium white', as the dioxide is called, coprecipitated, or mixed with barium or calcium sulphate or with lithopone as extending agents, forms the basis of many paints both for interior and exterior decoration. The same material, with its high index of refraction, brightness, fine subdivision and ready dispersion, is widely used in the manufacture of the better grades of paper, as a delustrant of rayon fibre and as a white colouring for rubber compositions, printing inks, plastic articles, soaps and cosmetics.

The phenomenal expansion of ilmenite production in India, from 400 tons in 1912 to over 250,000 tons in 1938, is a measure of the rise and development of 'titanium white'. By the end of 1938, over 1 million tons of ilmenite concentrates had been shipped abroad from the Travancore beaches and this had risen to over 2 million tons by 1945, while the grand total production up to the end of 1950 was 3,203,625 tons, of a nominal value of Rs3,16,11,439. The average annual output for the five years ending 1948 was 189,655 tons valued at Rs 20,22,487. The commercial production of rutile from the Travancore sands commenced in 1939, and up to the end of 1950, 10,670 tons valued at Rs15,55,184 had been recovered. From 1945, the Travancore State assumed control of the deposits and the sale of the products derived from them: the four firms formerly engaged in the business—Travancore Minerals Ltd, Hopkins & Williams (Travancore) Ltd, F. X. Pereira & Sons Ltd, and The Associated Minerals Co. Ltd—now work as agents of the State. The manufacture of titanium dioxide pigments was commenced in India during the autumn of 1951, at the works of Travancore Titanium Products Ltd.

THOUSAND
TONS



The world's annual average production of ilmenite for the five years ending 1938 was in the neighbourhood of 220,000 tons, and India alone was responsible for over 70 per cent of this, followed by Norway with 22 per cent, the remainder coming from Malaya (2.2 per cent), Senegal, Canada, Portugal, Egypt and Brazil. The whole of the Indian output was exported, mainly to the United States and the United Kingdom. The world's demand for ilmenite is increasing and is likely to continue to do so; at the same time, it is doubtful if India will retain so preponderating a position in the ilmenite trade of the future as she has occupied in the past, as competing sources of supply are developed. The output of ilmenite in the United States was under 5,000 tons a year in the period 1929 to 1938; war necessities compelled the opening-up of domestic resources, for ilmenite is not a rare mineral, so that today the U.S.A. heads the list, having produced 47 per cent of the world's total of 721,000 tons in 1948, against India's share of about 32 per cent.

TUNGSTEN

Wolfram, the chief ore of tungsten, is a mixture in any proportion of two minerals—ferberite, the tungstate of iron, FeWO_4 , and hübnerite, the tungstate of manganese, MnWO_4 ; the former contains 70 per cent and the latter 76.6 per cent of tungstic oxide WO_3 .

Tungsten is a hard, heavy, greyish-white element with the highest melting point, 3382°C. , of all the metals as well as the highest recorded strength. Its most familiar use, when drawn into wire of extreme thinness, is in electric light bulbs, but apart from this it is an essential material in very many forms of electronic equipment, including X-ray tubes of all kinds; gas discharge, fluorescent and projector lamps; radar and television apparatus; radio transmitting and receiving valves; ionization gauges and cathode-ray tubes, particle accelerators and mercury rectifiers. Tungsten is also employed in spark-plugs, ignition and other contacts and tips, welding electrodes, glass-to-metal seals and crucibles. For most of these uses it has no satisfactory substitute, yet, taken all together, they make little impression on the consumption of wolfram.

By far the greater proportion of the tungsten manufactured, estimated at 85 per cent of the total, finds its way into ferrous alloys, much of it as ferro-tungsten; some 8 per cent is made into tungsten carbide, while electronics and miscellaneous uses account for the remaining 7 per cent. Just as tungsten filaments revolutionized electric lighting, for a tungsten filament lamp is four and a half times as efficient as a carbon filament one, so the high-speed tungsten steels changed the whole character of the metal-cutting business. A machine using a tungsten steel cutting tool can be run at five times the speed possible with one using a carbon steel tool; furthermore, the tungsten tool maintains its cutting power

up to red heat and is self-tempering. Tungsten is of vital importance in industry, especially in times of war or preparation for war, and it has been truly stated that to deprive a nation of this metal would cripple its military power and ruin its industrial life in times of peace.

High-speed steels in common use contain 14 to 18 per cent of tungsten, with 4 per cent of chromium and 1 to 3 per cent of vanadium, though there are many variations on this formula in some of which molybdenum and cobalt also play a part.

Tungsten also enters into the composition of steels for armour plate, gun barrels, armour-piercing shells, railway lines, car springs, resistance wires, valves and valve seats of internal combustion engines, dies for wire drawing, drilling, cutting and grinding tools, knife and razor blades, hack saws, files and many other appliances. It is also a component of the stellites, more fully described under COBALT. Tungsten carbide is much harder than the hardest steels and, with metallic cobalt as a binder or matrix, it is formed into the tips of cutting tools which for some purposes are superior to the high-speed steels. This and similar materials made from tungsten and titanium carbides with cobalt, nickel or chromium, are also used for tipping rock drills, wire-drawing dies, cutting glass and porcelain and for general purposes where a super-hard substance is required. The quantity of tungsten consumed by the chemical industry is not large; cadmium tungstate is said to be used in preparing X-ray screens and sodium tungstate as a fire-proofing agent for cloth.

India's known wolfram deposits are restricted in size and low in grade; though capable of yielding a small production in emergencies they are not remunerative to mine in normal times. Thin veins and stringers of quartz, interbedded with mica and tourmaline schists of Dharwar age, at Agargaon, Nagpur district, Madhya Pradesh, yielded about 6 tons of the mineral in the period 1907 to 1914, and a further 8 tons were won in 1916 from small quartz veins in mica schists of the same age, at Kalimati, Singhbhum. Quartz veins traversing phyllites and quartzites at Chenndapathar, in the Bankura district of West Bengal, supplied 45 tons in the period 1942-3, and recently small amounts of wolfram and scheelite have been found by A. Hunday in a quartz vein north-north-west of Porah *pahar*, about 14 miles further north. The wolfram-bearing quartz-bodies in Aravalli schists at Jher and Palla, Ahmedabad district, Bombay, have proved too lean for exploitation. Wolfram has also been found at Kadavur and on the Ururakarad, in the Tiruchirappalli district of Madras.

On Rawat Hill, near Degana, Jodhpur, Rajasthan, wolfram occurs in veins and stockworks, with fluorite, biotite and small quantities of pyrite, chalcopyrite and the phosphates triplite and libethenite, penetrating both granite and Aravalli phyllites, into which it is intrusive. Here, as elsewhere, it is also found in the

local eluvial deposits into which it has been shed by denudation. Discovered in 1913 by Suraj Prakash, these deposits yielded 208 tons during World War I (1914-18): idle for seven years, production was started again in 1926, but only 30½ tons had been won up to 1933. Another blank period followed, until the stimulation of the demands of World War II led to a re-opening of the old workings in 1937. In 1942, a concentrating mill was erected at Rawat and the average wolfram content of the veins estimated at 0.65 per cent. During the decade 1937 to 1946, 307 tons were produced, but by 1946, output had fallen to 3 tons per annum and then ceased.

Scheelite, the tungstate of calcium, occurs in the gold-bearing quartz veins of the Kangundi area, east of Bisanattam, in the Chittoor district of Andhra. Old mine dumps in this region assayed 0.25 per cent tungstic oxide (WO_3) and 0.04 per cent metallic tin.

In Burma, quartz veins containing wolfram have been found at intervals over a distance of 750 miles, from the Yengan and Mawngang States of the Shan States in the north, through the districts of Yamethin and the State of Karenni, to the Thaton, Amherst, Tavoy and Mergui districts in the far south. In all these localities the wolfram and cassiterite-bearing veins are most intimately associated with the intrusive biotite granite which forms the cores of the mountain ranges of the Indo-Malayan system, stretching further south still through western Siam to the Malay Peninsula. In Lower Burma the granite is intruded into a series of shales, slates, argillites and agglomerates with subordinate quartzites, limestones and conglomerates, probably of Carboniferous age, and known as the Mergui Series. Both wolfram and cassiterite occur very sparingly as accessory minerals in the granite. They are also found in pegmatite and aplite veins and in the greisen bands which traverse it. The mineral-bearing quartz veins, however, are of greater importance, and they are to be found either in the granite, or penetrating its contacts with the sedimentary rocks, or, again, enclosed within the latter themselves at no great distance from the granite. Under the influence of denudation the veins shed their metallic contents into the eluvial deposits of the hillsides, from which a great deal of wolfram and tinstone have been won. The latter mineral also finds its way into the true alluvial deposits of the river valleys, where it can be recovered by dredging. The ores were formed partly under conditions closely allied to strictly magmatic ones, and were also produced by processes in which gaseous agencies, including compounds of fluorine and sulphur, to some extent played a part, and in rare cases by hydrothermal reactions which followed as a consequence of the former ones.

Along the scarps of the Shan Plateau, in the east of the Yamethin district, there are three areas where both wolfram and cassiterite occur in quartz veins and pegmatites of a coarse-grained biotite

granite and in the sedimentary rocks bordering its intrusion. The Padaigyaung-Peinnedaik-Hmanpya area is the richest of the three and one of its mines used to produce over 200 tons of concentrate per annum.

Karenni possesses the very important Mawchi mine, with an average annual production for the four years ending 1939 of 2,390 tons of wolfram and 2,733 tons of tin ore. Here, a large number of quartz veins, mostly under four feet in thickness, were mined both in the biotite granite and in the slates and argillites surrounding it. The accessory minerals are scheelite, tourmaline, pyrite, arsenopyrite, chalcopyrite and galena.

The Thaton district has two separate producing areas, the first on the long granite ridge of Zingzeik, with thin but persistent wolfram-bearing pegmatites and quartz veins, some traceable for three miles, both in granite and in hardened sedimentary rocks; the second on the western flank of the Dawna Range, not far from the Thailand border, where, once more, the normal biotite granite carries many quartz veins of the usual type. It is a richer area than the first-named, which possesses no great importance.

The leading wolfram deposits of the Mergui district are near Palauk in the north, and at Tagu in the valley of the Great Tenasserim river; here, as elsewhere, the veins are mined by underground methods during the dry season, but during the monsoon operations are largely confined to sluicing the eluvial deposits, both by the use of monitors and by hand methods, for the recovery of wolfram and tinstone, while the true alluvials of the valley bottoms are treated for their cassiterite contents.

The Tavoy district, with its area of 5,308 square miles, is by far the most important, and in 1939 there were over 190 producing concessions in it, compared with just over 100 in 1918. Most of them are shallow workings operated by methods primitive in the extreme, but others are deep mines under efficient technical control and equipped with modern concentrating plant. The largest mines are at Hermyingyi, Widnes, Kanbauk, Bwabwin, Byaukchaung, Pagaye, Wagon North and Paungdaw, and they are situated for the most part on or near the granite ranges which build up much of the district.

'The tungstate of iron, or wolfram sand,' wrote Dr Mason in his classical account of Tenasserim, published in 1849, 'much resembles tin and is found in most neighbourhoods where that ore is obtained.' The mineral was completely overlooked, however, until 1908, when it was rediscovered by J. J. A. Page of the Geological Survey of India. Mining commenced in 1910, and in 1911 an output of 1,300 tons made Burma the chief wolfram-producing country in the world at that time, a position she still occupied in 1914 when World War I found the British Empire dependent on Germany for its tungsten supplies. The situation was successfully dealt with, and between 1914 and the end of the war in 1918,

17,642 tons of wolfram, valued at £2,323,000, were exported to meet the demands of the Allied Powers for this martial metal, and of this quantity, 14,000 tons came from the Tavoy field alone. In the meantime high prices spurred on production in other countries and by 1916 the United States of America and Bolivia had both outstripped Burma. By 1917 large quantities of wolfram were being shipped from China, which rapidly became the largest producer in the world. Stagnation followed the boom but revival came again as the world's armament industry began to accelerate its preparations for World War II, and the graph of production on page 250 demonstrates better than a verbal description can the changes that took place, particularly how output rose to its peak of 7,052 tons in 1939, to be followed once more by the inevitable decline, intensified in this case by Burma being overrun by invading Japanese armies in 1942. In the following table, statistics of production from 1914 to 1940 are summarized.

PRODUCTION OF WOLFRAM IN BURMA, 1914-40

Period	Average annual Production* Tons	Average annual Value Rs
1914-18 ..	3,473†	....
1919-23 ..	1,726‡	15,80,725
1924-8 ..	955	4,86,752
1929-33 ..	2,355	13,58,206
1934-8 ..	4,418	56,04,736
1939 ..	7,052	....
1940 ..	4,172	....

* Concentrates with 60% WO₃.

† Includes 143.9 tons from India.

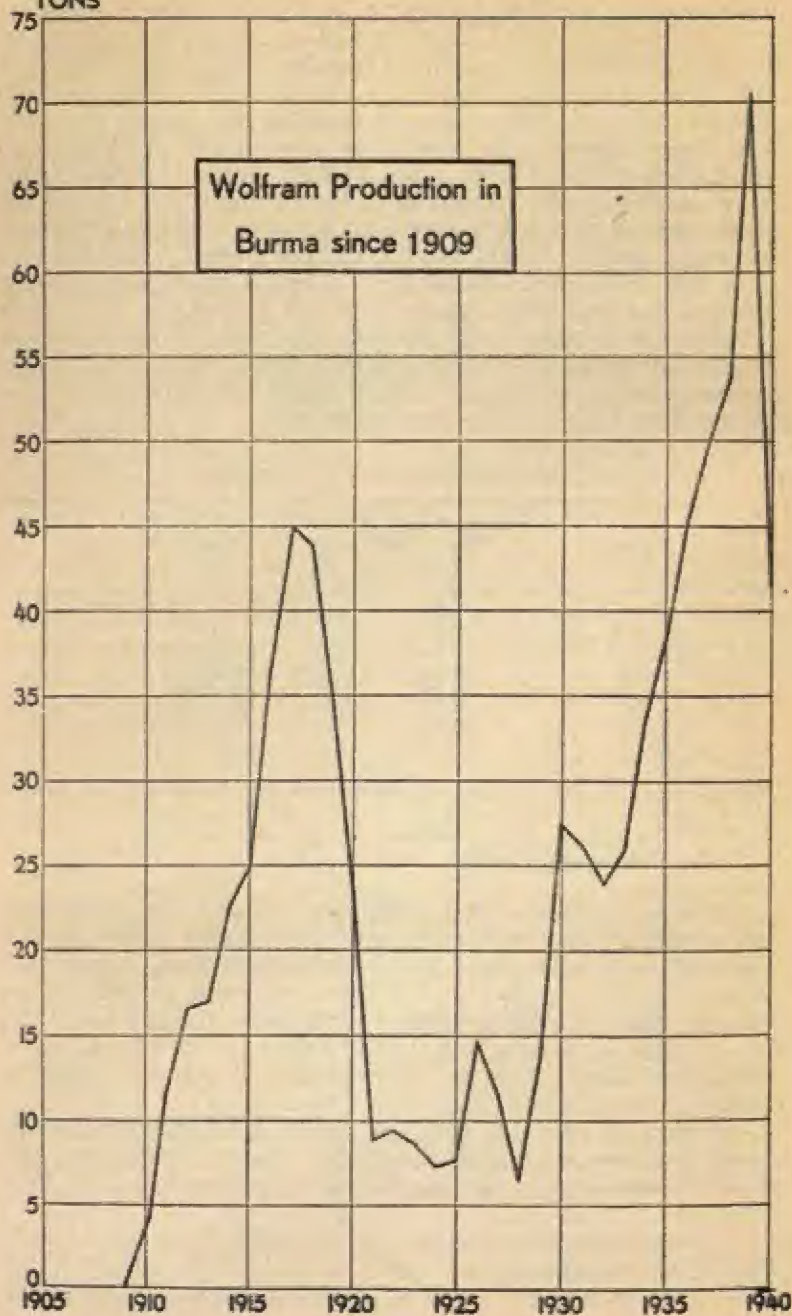
‡ Includes 47 tons from India.

No reliable figures are available for the post-war period until 1947, when Burma produced 349 tons of wolfram concentrates and 1,220 tons of mixed wolfram and tin ore concentrates. From 1948 to 1951, inclusive, 1,386 tons of wolfram were won, as well as 2,108 tons of mixed tin and wolfram concentrates in 1950 and 1951. The rehabilitation of the industry has been hampered by disturbed political conditions since the country attained its independence in 1948.

Between the years 1937 and 1946, India, as distinct from Burma, produced a total of 353 tons of wolfram, valued at Rs 8,04,550, and of this quantity 88 per cent came from Jodhpur and the rest from Bengal.

World production of tungsten ore in 1939, in terms of 60 per cent WO₃ concentrates, was approximately 34,000 tons, to which China contributed 33.6 per cent, Burma 20.8 per cent, Portugal

HUNDRED
TONS



11.4 per cent, the United States 11.3 per cent, Bolivia 9.8, Argentina 3.9 and Australia 3.0 per cent. Incomplete returns for 1948 reveal a world's estimated production (again omitting the Soviet Union) of some 26,500 tons, of which China was probably responsible for over 35 per cent, followed by the United States with 15 per cent, Portugal with about 10 per cent and then by Bolivia, Brazil and Australia, in the order named. The violent fluctuations of the demand for wolfram are well illustrated by the world's production figures for 1943, when over 56,000 tons were produced, compared with 1947, when less than 18,000 tons were recorded. Burma possesses great resources of tungsten ores, recoverable either independently, or as a by-product of tin mining, and it is hoped that the day is not distant when she will again enter the lists as a large producer of both these valuable mineral commodities.

VANADIUM

Vanadium is a soft, malleable, silver-white metal made by reducing its pentoxide with calcium but which at present has no industrial uses in its elementary form. The world's production of vanadium ores, reckoned in tons of the metal, averaged about 3,200 tons in the period 1939 to 1943, and had fallen to some 1,800 tons in 1950, though this takes no account of output in the Soviet Union or its satellite States. It is said that approximately 95 per cent of the total output is used in the alloying of steel and the remainder consumed for chemical purposes. The element is introduced into steel either in the form of the oxide, or as ferro-vanadium, and even in very small amounts imparts strength and ductility, producing at the same time a finer-grained product more resistant to shock, fatigue and torsional strains besides acting as a powerful deoxidizing agent. Vanadium steels, which may also contain one or more of a number of other alloying metals such as chromium, nickel, manganese and molybdenum, serve a large variety of special purposes, especially in the construction of axles, springs and other parts of motor vehicles and railway rolling stock. They are also used for boiler plates and pressure vessels, rock crushers, armour plate, gun shields and ordnance, as well as for constructional steels. Vanadium is sometimes added to cast iron, and it is an important ingredient of many of the high-speed cutting and die steels.

Vanadium pentoxide is a widely used catalytic agent in the synthesis of ammonia, and in the manufacture of sulphuric acid is displacing the more expensive platinum in the contact process. Some of its salts have limited uses in the paint and glass industries, in the printing and dyeing of fabrics and in pharmacy.

Vanadium-bearing titaniferous magnetites with a percentage of the pentoxide (V_2O_5) varying from 0.8 to 3 per cent occur near the southern border of the Dhalbhum subdivision of Singhbhum

and extend into Mayurbhanj, the more important localities including Kumhardhubi and Dublabera. Similar ores have also been found near Nuasahi in Keonjhar. According to J. A. Dunn and A. K. Dey, they are in very close association with basic and ultrabasic rocks, sometimes altered to serpentines, more often to epidiorite, but, as a rule, little changed from the original basic gabbro of which they are magmatic segregations. The vanadium is contained in a new mineral named coulsonite, a variety of magnetite, $\text{FeO} \cdot \text{Fe}_2\text{O}_3$, in which part of the ferric iron is replaced by vanadium, giving the formula $\text{FeO} \cdot (\text{FeV})_2\text{O}_3$. Since its discovery in India, this mineral has been found in Ontario, Canada and in New York State of the United States of America.

A green mica distributed in a quartzite at Mahalgaon, Bhandara district, Madhya Pradesh, contains 0.48 per cent of vanadium oxide (V_2O_5) and 2.74 per cent of chromium oxide (Cr_2O_3): according to S. K. Chatterjee it appears to be intermediate in composition and optical properties between fuchsite, the chromiferous mica, and roscelite, the vanadium-bearing mica. Such roscelitic micas also occur in the kyanite and sillimanite-bearing rocks of the Bhandara district. Roscelite, with 1.5 to 5 per cent vanadium, has been used as a source of vanadium in the United States.

Vanadiferous magnetite with an average content of 0.56 per cent of vanadium pentoxide (V_2O_5) and up to 0.85 per cent of chromic oxide (Cr_2O_3), occurs to the north of Godasahi, Nilgiri, Orissa, where, according to H. Nandi, about 200,000 tons are available. A smaller occurrence with 1.08 per cent of the vanadium pentoxide and 1.27 per cent of the chromium oxide (Cr_2O_3), is known at Rangamati, in the same area. Vanadiferous magnetite, amounting to about 50,000 tons according to B. C. Gupta, occurs as lenticular bands in the ultrabasics at Nausahi in Keonjhar district, also in Orissa. Two picked samples gave 0.92 and 1.84 per cent of V_2O_5 on analysis.

The world's vanadium supplies are drawn for the most part from the patronite (vanadium sulphide) deposits of Minasragra in Peru, from the carnotite (hydrated vanadate of uranium and potassium) and roscelite deposits of Colorado and Utah, from various vanadates of lead found in the oxidized portions of the lead-zinc ore deposits of Broken Hill, in Northern Rhodesia, and from similar ores of the Otavi region of South-West Africa.

The ashes of certain coals, hydrocarbon oils and asphalts contain comparatively large amounts of vanadium, which is profitably recovered from the soot of furnaces burning such fuels. It has been found in the ashes of lignite at Neyveli, South Arcot, Madras, and reported (and denied) that the ash from the Varkala lignites of Travancore contains 2 per cent of vanadium oxide.

The possibility of inaugurating a vanadium industry in India depends on the successful development of a method of its recovery from the titanium-bearing magnetites, but further investigation of

vanadium content of the green micas, of the ashes of Indian coals and oils, and of its occurrence in laterites, bauxites and blast-furnace slags, might lead to a modification of this view.

ZIRCONIUM

The two minerals baddeleyite (or brazilite), the natural oxide of zirconium (ZrO_2), and zircon, zirconium silicate (ZrSiO_4), with 60.2 per cent of the metal, compared with 74.0 per cent in the oxide, supply most of the world's requirements of zirconium and its compounds at the present time, requirements which have grown rapidly in recent years and are likely to expand. Baddeleyite was discovered in Ceylon, in the gem gravels of Ratnapura, but is only of economic importance in Brazil. Zircon is one of the commoner accessory minerals in all kinds of igneous rocks, but especially of granites, pegmatites and nepheline syenites. From the pegmatitic varieties of the latter group as well as from other sources come the brilliant, precious kinds of Ceylon and Burma, described under GEMS. The sand derived by the weathering of the zircon-containing rocks, after their lighter portions have been washed away, contains concentrations of the heavier, more resistant minerals such as zircon, monazite, rutile, ilmenite and garnet. Thus it comes about that zircon is obtained as a by-product in the winning of monazite and ilmenite from the fine, granular, black sands of the Travancore coast, in which it occurs to the extent of about 6 per cent. Zircon production commenced in 1922 and from that time until 1946, when the publication of further statistics ceased for strategic reasons, 38,094 tons, valued at Rs 14,61,000 approximately, had been won. For the same reasons it is not permissible to discuss the probable future of the industry here, except to add that large reserves of zircon exist, sufficient to meet any domestic demand that is likely to arise either now or in the distant future.

Zirconium is a soft, lustrous, greyish-white metal, produced either by the thermal dissociation of its tetraiodide, or by the reduction of its tetrachloride with magnesium, and is obtainable in commerce in the form of powder, sheet, wire or rods. It is very reactive with both nitrogen and oxygen and burns brightly when heated in the air, a property accounting for its use in flashlight powders, primings for explosives, and in the removal of traces of gases from vacuum devices of various kinds. The metal is said to have great resistance to the attack of alkalis and is used in parts of rayon-spinning machines. Alloys such as ferro-zirconium and zirconium-ferro-silicon are used to remove oxygen, nitrogen and non-metallic impurities generally from molten steel, and in so doing to give the finished product greater uniformity in composition and grain. Ferro-zirconium is made in the electric furnace by the reduction of mixtures of zircon and iron ore, or by the aluminothermic smelting of the mixed oxides. As an alloying addition to

TONS
7000

6500

6000

5500

5000

4500

4000

3500

3000

2500

2000

1500

1000

500

0
1920

1925

1930

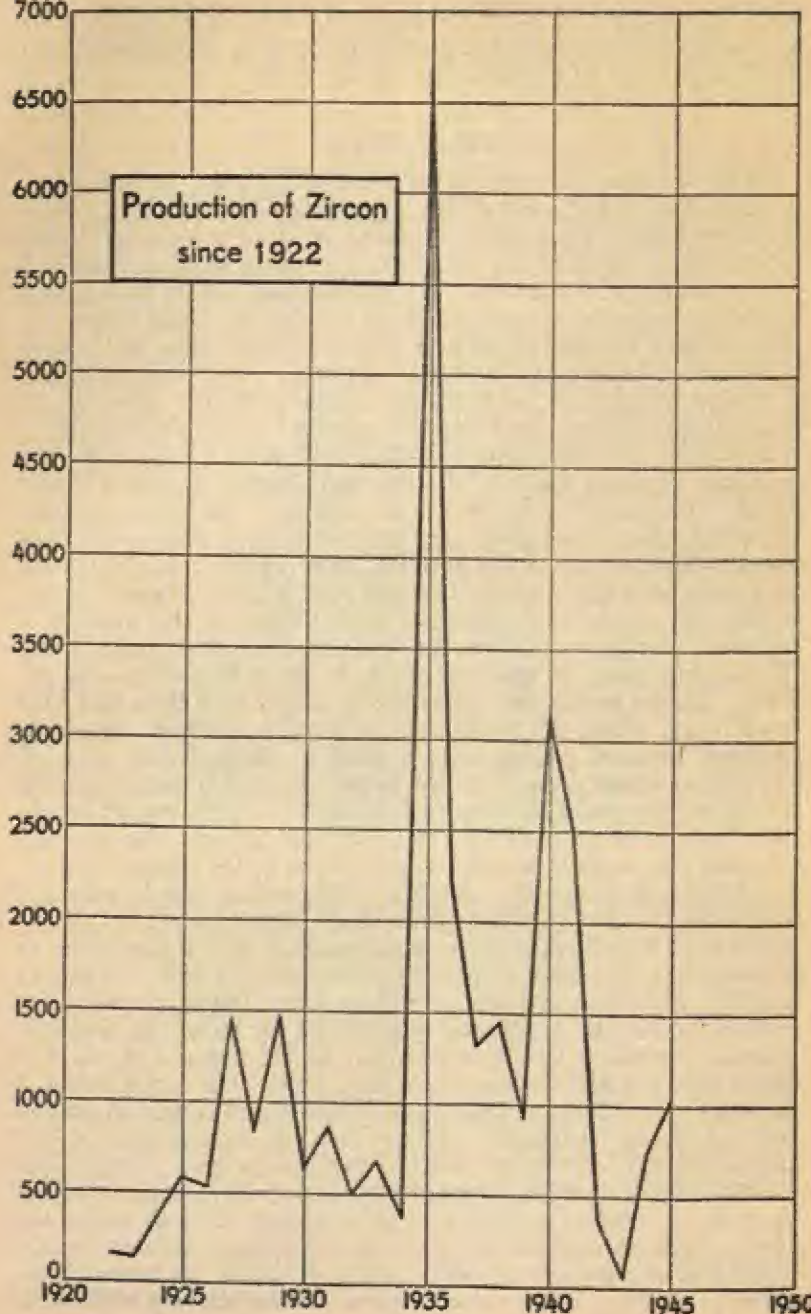
1935

1940

1945

1950

Production of Zircon
since 1922



special steels, zirconium increases ductility and resistance to shock and fatigue; such steels have been employed in the manufacture of light armour-plate and projectiles. Fractional percentages of the metal added to the nickel-chromium alloys lengthen their operational lives in industrial and domestic heating apparatus. The strength of copper is very greatly increased by the addition of from 5 to 10 per cent of zirconium, and it forms hard alloys with nickel which have been used as cutting tools. Its alloys with magnesium are referred to under MAGNESIUM and CERIUM, the outstanding effects of the metal being evident in intensive grain refinement, improved corrosion resistance and better workability. A recent authority has stated that the zirconium-magnesium casting alloys are becoming increasingly popular both in the United Kingdom and abroad, and that virtually every new aircraft flown in England at the present time contains an appreciable number of zirconium alloy castings, either in its structural components or in its engines, or in both.

The rare element hafnium is a constant associate of zirconium in its natural compounds, their relationship having been compared to that existing between niobium and tantalum or between adjacent members of a rare earth series; belonging to the same group in the Periodic Classification, they possess similar chemical and physical properties, and the separation of hafnium from zirconium is a tedious process. This has a bearing on the potential use of zirconium in atomic energy developments, particularly as a sheathing metal for the natural uranium rods in nuclear reactors, or as a moderator. Sir John Cockcroft has stated that for these purposes zirconium with its low absorption capacity for neutrons must be free from the strongly absorbent hafnium.

The natural silicate zircon is stable to about 1800° C., when it dissociates into zirconia, one of the most refractory substances known, and a siliceous glass. It is being employed increasingly in a number of metallurgical processes further described under REFRACTORIES. Graded zircon sands, with the addition of a suitable bond, make useful cements for coating the surfaces of less resistant refractories. Zirconia is employed in the manufacture of special porcelains, such as those used for sparking-plugs, where its high dielectric strength and power to resist temperature changes under rigorous conditions are distinctive. It is also a component of some types of heat- and chemical-resisting glasses, and has other applications including its use as a white opacifier in vitreous enamels and ceramic glazes, where it is said to be replacing both tin and anti-mony compounds, as well as in white paints and lacquers. It is also incorporated into some forms of white rubber and leather as well as into polishing and toilet powders. A recent official American report classifies the existing industrial uses of zircon in that country as follows—refractories, 45 per cent; foundry facings, 19 per cent; porcelain enamels, 7 per cent; metals and alloys,

7 per cent; pottery, 7 per cent; electrical and chemical porcelain, 3 per cent; glass, 1 per cent; miscellaneous, 11 per cent.

Most of the world's zircon supply is at present derived from naturally concentrated beach sands, recalling those of Travancore, which are situated along the coast and its accompanying dunes between Coffs Harbour in New South Wales and Stradbroke Island in Queensland, Australia. From this source alone came almost 22,000 tons out of an estimated world's total of between 26,000 and 27,000 tons of zirconium minerals in 1948. The Australian consumption of zircon is small and by far the greater part of the production is exported. Brazil is the second largest source of supply and in 1948 gave about 3,500 tons to the world's markets, mainly of baddeleyite. Other producing countries include the United States of America, French West Africa, Egypt, Madagascar and Norway.

CHAPTER VI

THE LIGHT METALS

ALUMINIUM

ALUMINIUM, the silvery ductile metal with a density about one-third that of steel or brass, owes its industrial importance to its lightness and the ease with which it can be fabricated—rolled into sheets, strips, plates and sections; drawn into tubing and wire; forged, cast, extruded or powdered; joined, extended, spun or coloured after anodizing. It alloys readily with other elements, particularly copper, magnesium, silicon, manganese and zinc, forming both 'wrought' and 'casting' alloys, many of which are harder, stronger and tougher than the pure metal itself. It possesses marked corrosion resistance, high electrical and thermal conductivity and is a good reflector of light and radiant heat.

Though it is the most abundant metal in the crust of the earth, it is troublesome to separate from its natural compounds and sixty years ago was little more than a laboratory curiosity. By the end of the first world war in 1918, the world's production of the metal was only about 150,000 tons per annum; in 1937 this had risen to nearly half a million tons, in 1941 to almost one million tons, and in 1943 not far short of two million tons; in 1950 approximately one and a half million tons were made, excluding the production of the U.S.S.R. and her satellite countries. The expansion during the period of the second world war was in great measure due to martial demands from the aircraft industry, naval dockyards and ordnance factories.

The group of alloys of the duralumin type, which contain 3 or 4 per cent of copper and smaller quantities of magnesium and other metals, are used in vast quantities in the framework of aircraft. Threequarters of the frame weight and up to one half of the weight of engines and propellers of a modern aeroplane are said to be made up of aluminium alloys. Modified aluminium-silicon alloys are sand- and die-cast for engine mountings, cylinder blocks, pistons, gear boxes, crank cases and bearing housings for internal combustion engines. The wrought aluminium-magnesium alloys, with 2 to 7 per cent of magnesium and under 1 per cent of manganese, combine high strength with corrosion-resistance and are used in the construction of marine auxiliary vessels. During the last war other alloys were developed for aircraft armour, portable landing mats for air strips and troop shelters, while aluminium foil

was used in large quantities to baffle enemy radar observations. Aluminium alloys today find increasing outlets in the construction of road and railway vehicles and their fittings, as well as in structural engineering of all kinds including that of prefabricated buildings and bridges.

Aluminium cable, reinforced by a steel core, is now a standard material for overhead electrical transmission lines, as in the case of the British National Grid. It also has advantages over lead as a sheathing for other cables in special positions and as flashings for roofs and walls. There are now few branches of human activity into which the metal does not enter; its multifarious uses range from mining equipment to domestic cooking utensils and household appliances, from bicycles to beer barrels, from corrugated roofing sheets to the 'silver paper' wrappings of food and confectionery, or to imitation gold ornaments fashioned from aluminium bronze.

Aluminium powder is a very powerful reducing agent and is the foundation of the aluminothermic process for the production of metals, such as chromium and manganese, as well as special alloys such as ferro-niobium. The process is also used for the welding of rails and heavy steel sections. According to Dr G. P. Contractor, the use of aluminium is an almost universal practice in the manufacture of rimming steel. Paint made from aluminium powder is unusually durable and possesses both decorative and preservative qualities.

The principles of the processes used in the extraction of aluminium today are substantially the same as those discovered by G. W. Hall, a 22-year-old student, in 1886: the electrolysis of alumina (aluminium oxide), in a bath of molten cryolite. The ore bauxite was in the early days, and still remains, the essential raw material from which alumina is prepared. For the profitable operation of the process large amounts of electrical energy are required. Dr T. T. Read, Professor of Mining in Columbia University, recalls that it takes 25,000 kilowatt-hours of electrical energy to produce a ton of aluminium and since $1\frac{1}{2}$ pounds of coal are required to generate a kilowatt-hour in an average steam power plant, the equivalent of twenty times as much coal (without any by-product recovery) is required to make a ton of aluminium as a ton of iron. This is on the assumption that a ton of coal (in the form of coke from which the by-products have been recovered) is sufficient to produce a ton of iron. This is the reason why aluminium reduction works are usually erected at or near hydro-electrical generating stations, and particularly in situations where there is little other demand for the power and it is correspondingly cheap. Four tons of bauxite are needed to make two tons of alumina, to yield in its turn one ton of the metal.

As long ago as 1883, F. R. Mallet of the Geological Survey of India found that a variety of laterite from Jabalpur district, in Madhya Pradesh, contained a large proportion of aluminium and,

in 1903, H. and F. J. Warth proved that many Indian laterites from various parts of Bihar, Bombay, Madras, Vindhya Pradesh and Madhya Pradesh are, in reality, bauxites. Sir Cyril Fox's memoir on the bauxite and aluminous laterites of India appeared in 1923.

Bauxite is not a distinct mineral species but rather a generic term for a number of aluminium hydroxides often in a colloidal condition, including diaspore (common in the Kashmir occurrences), boehmite, and gibbsite (common in both pisolites and matrices of the Indian material generally). Indian geologists apply the term to those varieties of laterite sufficiently rich in aluminium oxide, and free enough from undesirable impurities, to be acceptable as an aluminium ore. Laterite is a residual product of rock decay in tropical climates subjected to alternating wet and dry seasons, during which silica, lime, magnesia and alkalis are removed in solution and the iron, aluminium, manganese and titanium are left behind and rearranged, usually as hydrated oxides. The greater proportion of the larger spreads of laterite are far too ferruginous to be of any value as aluminium ore, though exceptionally they have been utilized both as ores of iron and of manganese. Between laterite and bauxite there is no sharp dividing line and one may gradually pass into the other. Almost all the bauxites (aluminous laterites) are of primary origin and were formed in the situations that they now occupy; moreover, most of the better-known occurrences are connected with the decomposition of the basaltic flows of the Deccan Trap.

It is customary to regard members of the group as ferruginous laterites when the percentage of iron is greater than 40 per cent, and as aluminous laterites (or bauxites) when the percentage of aluminium passes the same figure. The flat-topped hills so characteristic of regions occupied by Deccan Trap, and particularly the uppermost 10 feet or so of them, are favourable locations for bauxite occurrences. It is common to find that the very top of a scarp is made of the iron-bearing variety of laterite, but just under this ferruginous mantle, the best grey bauxite occurs at depths of from 1 to 5 feet. If an extensive plateau exists, good bauxite is frequently found at the commencement of the stream courses which drain it, either in the bed itself, or close to its margins, taking the form of a rough pavement. In such instances there may be a slight development of the red ferruginous covering as well.

Recent investigations have resulted in the following estimates of the reserves of titaniferous bauxite, containing over 50 per cent of alumina, on such flat-topped, laterite-capped plateaus or similar situations. (See table on p. 260.)

It is to be noted that India's reserves of bauxite containing less than 50 per cent of alumina are several times this total of 25½ tons. High-grade ore is also known to occur in Rewa, Vindhya Pradesh, and further deposits, usually of lower grade, are to be found in Ratnagiri and Gujerat, Bombay; Bastar, Madhya Pradesh; Bhopal;

THE LIGHT METALS
RESERVES OF BAUXITE IN INDIA
(with 50% or more Al_2O_3)

STATE	DISTRICTS	RESERVES (Tons)
BIHAR	Ranchi and Palamau	9,000,000 (approx.)
MADHYA PRADESH	Surguja-Jashpur-Bilaspur ..	6,374,000
	Balaghat-Mandla-Kawardha ..	2,135,000
	Bilaspur-Shahdol (Amarkantak area)	520,000
	Jabalpur	525,000
BOMBAY	Belgaum	670,000
	Kolhapur	2,142,000
MADRAS	Salem (Shevaroy Hills)	2,000,000
MYSORE	Bababudan Hills	100,000
ORISSA	Sambalpur-Kalahandi	200,000
KASHMIR	Jammu and Poonch	2,000,000 (approx.)
	TOTAL	25,766,000 tons

Note :—The Shahdol district into which the Amarkantak plateau stretches from Bilaspur lies in Vindhya Pradesh.

Bikaner, Kotah and Tonk, Rajasthan. Quite recently bauxite enrichments have been discovered on Tungar Hill, near Bassein, Bombay, where there are about 100,000 tons of all grades with 30 to 50 per cent Al_2O_3 ; and near Mewasa in Nawanagar, Saurashtra, where samples analysed 42 to 64 per cent Al_2O_3 , though the extent of the deposit has not yet been proved. According to the *United States Bureau of Mines Mineral Trade Notes* Vol. 36 (1), 1953, the Geological Survey of Pakistan reported the discovery in 1951 of about 500,000 tons of bauxite along the North-West Frontier Province and Kashmir border.

Quarrying for bauxite started in the Katni district of Madhya Pradesh in 1908, and in the Khaira district of Gujerat in 1920, in other districts of Bombay such as Thana and Belgaum considerably later and on a large and continuous scale in Bihar in 1946. Other areas contributing to the total include Nagod in Vindhya Pradesh and various districts of Mysore and Madras. The total recorded output between 1909 and 1950, inclusive, was 415,260 tons, most of which was drawn from the Katni district, until the manufacture of aluminium was successfully inaugurated, since when greater attention has been directed to the Lohardaga deposits of Bihar. Up to that time the bauxite had been used for refining kerosene, manufacturing alum and making refractory products. Of the 113,547 tons won during the decade 1934 to 1943, Madhya Pradesh contributed 94.3 per cent and Bombay 5.5 per cent, but in the next quinquennium, 1944 to 1948, with its total of 83,127 tons, the percentage from Madhya Pradesh had dropped to 65.5, Bihar had entered the list of producers with 21 per cent, while Vindhya



Indian Aluminium Co., Ltd.

BAUXITE QUARRY ON THE SCARP OF A PLATEAU, CAPPED BY LATERITE, NEAR LOHARGADA, BIHAR

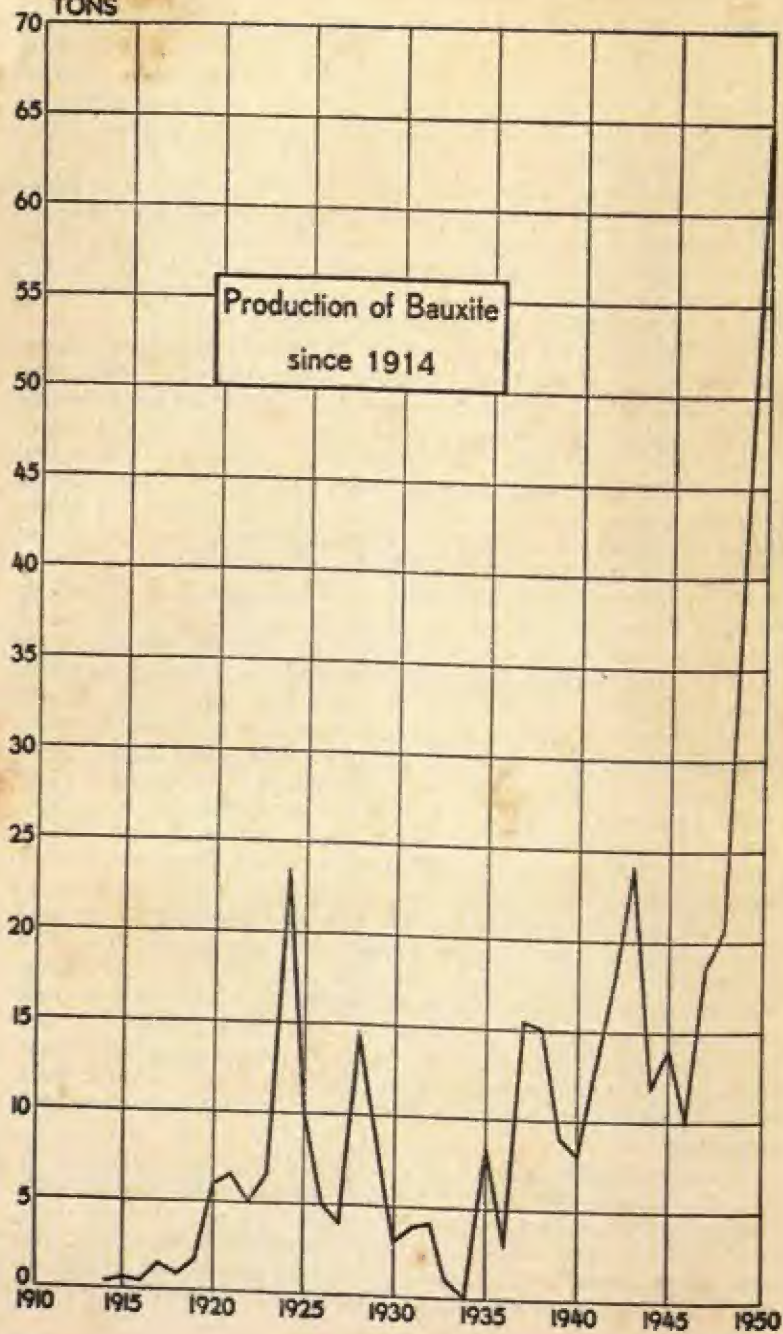


Pradesh and Mysore added the remainder. In 1949 and 1950 of 106,940 tons returned, Bihar gave 51·6 per cent, Madhya Pradesh 43 per cent while Bombay and Madras followed with 3·1 and 2·3 per cent respectively. Of the 64,400 tons raised in 1950, 23,000 tons went to the aluminium reduction works and the remainder was mainly consumed in the manufacture of alum and related chemicals, high alumina cement, refractories, and in kerosene refining. For some years the average declared 'pit's mouth' value was about Rs 3-5-0 per ton, though this was little guide to the real worth of any particular variety and probably merely represented the approximate cost of extraction; by 1950 the average declared value had risen to Rs 12-10-0 per ton.

The first ingot of aluminium made in India from Indian bauxite was cast on 10 July 1944 at the works of the Aluminium Corporation of India Ltd, a company registered in 1937 which has its works at Jaykaynagar, near Asansol, West Bengal. These have a capacity of 3,000 tons of sheets and circles per annum and rely on steam power. The associated alumina plant commenced operations in October, 1942. Another concern, The Indian Aluminium Company, has its bauxite quarries at Lohardaga, its alumina works at Muri, in the Ranchi district of Bihar, its hydro-electric reduction works at Alwaye, near Alupuram in Travancore and its rolling mills at Belur, near Calcutta. It has been producing the metal since 1943, but as the last war interfered with the erection of its plant at Muri, imported alumina was used for the purpose. The projected capacity in this case is 5,000 tons per annum, but is unlikely to exceed 2,700 tons per annum until more power is made available from the Pallivassal hydro-electric undertaking. The combined production of the two companies has grown from 1,272 tons in 1943 to 3,594 tons in 1950, with a total production of 22,170 tons of aluminium over that period. In 1951, the Planning Commission considered it necessary that the output of aluminium should be increased within the next five years to 25,000 tons per annum. The two producing companies are therefore required to increase their capacity to 5,000 tons per annum each, and another reduction works is to be installed in the Hirakud area with a yearly output of 15,000 tons. Plant for the manufacture of aluminium wires and cables has been erected at Kundara, Travancore, while a factory to produce aluminium paste for paints has been constructed near Bombay. Aluminium hollow-ware has been made in India from imported metal and scrap since 1912, when a small plant was erected in Madras.

For the decade ending 1938, India's imports of aluminium in the form of unwrought ingots, circles, sheets and other manufactures, averaged 3,636 tons yearly, but during the three years ending 1946, they reached 5,423 tons per annum, valued at Rs 87,62,392. In 1950, 7,052 tons of wrought and unwrought aluminium, valued at over Rs 2 crores, were imported. This gives some idea of the scope

THOUSAND
TONS



for the development of the indigenous aluminium industry, without considering the substantial increase to a consumption of 30,000 to 50,000 tons per annum within the next ten or fifteen years which is anticipated. The economics of aluminium manufacture in India have been discussed by Dara P. Antia, of the Directorate of Industry and Supply, who has concluded that unless the industry is backed by concerns already engaged in it elsewhere its rapid growth in this country is doubtful.

The world's annual production of bauxite in the period 1934-8, before the last war, was in the neighbourhood of $2\frac{1}{2}$ million tons, supplied by France, Hungary, the United States of America, British Guiana, Yugoslavia, Italy, Dutch Guiana, the Soviet Union, the Netherlands East Indies and Greece in order of magnitude of output, and two-thirds of this total is believed to have been turned into metallic aluminium. The war stimulated production enormously; by 1941 it had reached over $6\frac{1}{2}$ million tons, the average for the five years ending 1943 being 7,017,000 tons approximately, according to statistics issued by the United States Bureau of Mines, which do not include countries with an annual output of less than 100,000 tons. Production during that period was shared as follows: United States 29 per cent of the total, France 10 per cent, British Guiana 15 per cent, Surinam 14.7 per cent, Hungary 12.7 per cent, Italy 6.5 per cent, U.S.S.R. 4 per cent, Yugoslavia 3.7 per cent, Netherlands Indies 3 per cent and the remainder divided about equally between the Gold Coast and Ireland. The world's production in 1948 was considerably over 8 million tons, about half of which came from the Guianas and under one quarter from the United States of America. The U.S.A. is the largest aluminium producer in the world and is followed by Canada, which relies mainly on ore from British Guiana.

The use of bauxite in the manufacture of chemicals is described under ALUM, but it remains to add that the varieties most suitable for this purpose should contain less than 3 per cent of ferric oxide. Chemical grades of bauxite with 55 to 58 per cent of alumina and 1.5 to 2.5 per cent of ferric oxide command prices at least half as high again as the cruder kinds.

The crystalline variety of alumina, corundum, is a natural abrasive second only to the diamond in hardness, and its distribution in India is described under ABRASIVES. Artificial corundum is made by fusing bauxite in the electric furnace and for this particular purpose some of the lower grades of the mineral are acceptable, the finished product being marketed as powder, grains and special shapes under a great variety of trade names.

The use of bauxite in the manufacture of refractory bricks and other articles is described under REFRACTORIES. The aluminous cements, made by grinding fused mixtures of bauxite and chalk, possess very high early strength and are immune from many forms of chemical action which attack Portland cement and

concrete made from it. The rapid-hardening properties, the resistance to sea-water, and to ground-water containing sulphates in solution, together with the general impermeability of aluminous cement and concrete made from it, have led to their extended use in the construction of reservoirs and foundations in marshy conditions, of piers and harbour works, of pipes and sewers for large drainage schemes, of internal linings for water tunnels, of power-station flues and of situations in general where strength is desirable in the shortest possible time. We are indebted to the Lafarge Aluminous Cement Co. Ltd, the makers of 'Ciment Fondu', for this information.

Bauxite filters are installed in oil refineries for the purification and decolorization of kerosene, and the mineral from the Khaira district of Bombay has been largely used for this purpose.

Bauxite production in India will expand with the growth of the aluminium industry, especially as the imports of foreign alumina ceased in 1950, and with the further utilization of the mineral for the various purposes described.

MAGNESIUM

Magnesium is a silvery white, ductile metal which, with a density of 1.74, compared with that of 2.7 for aluminium, is also an uncommonly light one, but, although its compounds abound both in the crust of the earth and in the waters of the sea, it is not easy to extract from them. Its strong affinity for oxygen causes it to burn fiercely with an intense white light and accounts not only for its uses in photographic flashlight powders and as a deoxidizing agent in the refining of other metals and alloys, but also for its presence in the incendiary bombs of warfare. Incendiary bomb casings are alloys of magnesium with 5 to 7 per cent of aluminium, and the powdered metal is also a constituent of the filling of some types. The same affinity for oxygen leads to the employment of the metal in the form of ribbon or wire to remove the last traces of gases from radio valves.

It is made on a commercial scale by the electrolytic reduction of fused magnesium chloride, obtained from sea-water, natural brines or bitters, and also by the thermal reduction of its oxide, magnesia, by means of ferro-silicon, coke or calcium carbide. The minerals used as a starting-point include magnesite, the carbonate, MgCO_3 , with 28.9 per cent magnesium; dolomite, magnesium-calcium carbonate, $\text{MgCO}_3 \cdot \text{CaCO}_3$, with 13 per cent of magnesium, and brucite, magnesium hydrate, Mg(OH)_2 , with 41.6 per cent of the metal. The carbonates magnesite and dolomite are sources of basic refractory materials and are further described under REFRACTORIES. The silicate olivine $2(\text{MgFe})\text{O} \cdot \text{SiO}_2$, its decomposition product serpentine, and the hydrated silicate talc, also have refractory and other industrial applications and are considered separately.

The pure metal is of little use in engineering, but its commercial alloys, with a general specific gravity of 1.84, are the lightest structural materials available, being about one quarter the weight of iron and two-thirds that of aluminium alloys. They are indispensable for aircraft frames, landing wheels, propellor blades, and aero-engine castings. They are also employed in gear-box castings as well as for tractor wheels, bodywork and other parts of motor vehicles of all descriptions. Their light weight, strength and excellent machining properties are noteworthy, whilst the strength-to-weight ratio of their castings is the highest for all cast materials, making them of great present and potential importance in many branches of engineering. For the construction of portable tools, machine parts and textile machinery and for all kinds of appliances that have to be moved, either manually or mechanically, they possess definite advantages. The high electro-chemical equivalent of magnesium has led to its growing use in the anodic protection of underground oil pipelines, and the buried foundations of cast iron and steel structures, for by this means corrosion which cannot be prevented is largely brought under control. Considerable quantities of pure magnesium are consumed in alloys of aluminium, for from 2 per cent to 10 per cent of the metal in their composition renders them completely resistant to corrosion by sea-water.

Aluminium, zinc and manganese are the metals most widely used in the past for alloying with magnesium itself, the two former for imparting hardness and other improved physical properties, and the latter as a corrosion-resisting agent. The chief alloys are of the quaternary type and contain 3 per cent to 10 per cent of aluminium besides zinc and manganese, but many different varieties are made, each designed for its own special purpose. The wrought forms are available as rolled sheets, plates and strips; extruded bars, sections and tubes, pressed or impacted forgings; rolled bars and sections: other types are made for use in sand, gravity-die and pressure-die castings. Only one of many examples can be quoted here, the alloy known as 'Elektron A8' which contains about 8 per cent of aluminium, 0.5 per cent of zinc and 0.2 per cent of manganese, and which, after solution heat-treatment, develops remarkable resilience and high shock-resistance, so that it is almost exclusively used in the construction of the landing wheels of aircraft.

More recently zirconium and the rare earth metals have been developed as magnesium alloying agents by Magnesium Elektron Ltd, to whom we are indebted for particulars. These new alloys are remarkable for their extremely fine grain and improved properties; the ternary casting alloys with about 0.7 per cent zirconium and 2.5 to 6.5 per cent zinc, possessing proof stresses nearly double those of the magnesium-aluminium-zinc series, while the related wrought types, with zirconium, exhibit substantial improvements over those of the older group. These alloys have actually been

cast into ingots in normal steel ingot moulds and rolled down into bars in rolling mills in exactly the same way and at the same speeds as the steel ingots replaced. The quaternary alloys contain magnesium, zinc, zirconium and 2.5 per cent to 4 per cent of the rare earth metals ('cerium'), the introduction of the latter having been found to confer a remarkable resistance to creep at elevated temperatures. They can also be cast pressure-tight, in most complicated shapes to withstand high pressures, and have proved capable of heavy duty on full loads at elevated temperatures. Magnesium is so reactive chemically that it combines easily not only with the oxygen of the air to form its oxide, but also with the nitrogen to form its nitride; in melting it or its alloys it is essential to protect them completely to prevent combustion. This is done by means of special fluxes, mainly mixtures of the chlorides of magnesium, calcium, sodium and potassium, yielding fluxes of fluid types, or these chlorides to which magnesia and calcium fluoride are added to give viscous and thicker mixtures. Care is also needed in the preparation of the moulding sands for the casting processes, but treated correctly the metal and its alloys can be handled safely without any undue risk of fire. Unprotected magnesium-base alloys are very resistant to atmospheric attack except in salt-laden atmospheres, but like other erosive metals, such as iron and steel, they must be protected by suitable paints if the maximum immunity is to be achieved.

The second world war created an unprecedented demand for magnesium and it was met by a phenomenal increase in production, which increased from about 32,000 tons in 1939 to 265,000 tons in 1943, when in the United States of America alone 63 plants were either making, or preparing to make, the metal and over 183,000 tons were produced. Mounting stocks and decreasing requirements for war materials soon made their effects apparent, a number of reduction works were closed, and by 1945, as far as the States were concerned, magnesium was plentiful for all war requirements with only 50,000 tons of the total 300,000 tons capacity in use. The end of the war found the world supplied with a production capacity far beyond its existing peace-time needs, together with a legacy of stocks and secondary metal which had not been entirely absorbed by 1950. In that year it was reported that only one primary producer was in part-time operation in North America, with an output of some 10,000 tons per annum. The world's production for 1950 has been provisionally estimated at about 20,000 tons, excluding the Soviet Union, and even this figure represents an increase of nearly 40 per cent on the output for 1949. To what extent the growing rearmament programmes of the nations will affect the situation is not yet clear.

It is for these reasons that the question of magnesium production in India, despite her abundant supplies of high-grade raw materials, should be approached with caution, and the wise recommendation

of the Non-Ferrous Metal Industries Panel in 1947, to defer the matter for the time being, upheld.

Besides its uses as a refractory material, dolomite serves many other purposes; some varieties are used in iron smelting as fluxes, others as building stones, statuary marbles and lithographic stones. The mineral is suitable as a source of carbon dioxide and of basic magnesium carbonate, which blended with asbestos is employed as a heat-insulating covering for boilers and hot-pipe laggings.

Magnesite and dolomite are the starting materials for the preparation of many magnesium salts, which are essential chemicals in many industries including ceramics, glass manufacture, paper making, sugar refining, as well as in fire-resisting paints, water treatment agents, the glue and rubber trades and pharmacy. The chloride of magnesium is of special importance in India, where it is widely employed in the sizing of cotton yarns before they are woven into cloth, particularly in the hot and dry textile centres where its hygroscopic character promotes softness and pliability in the mill yarns. This country has for many years produced its own supplies of this compound and its manufacture is described separately in Chapter XIV. The application of the chloride in the preparation of oxychloride cements is also described elsewhere, but it may be added here that jointless composition floorings of these materials are extensively employed in India for railway carriages and vans. Magnesium chloride has other uses, including the part it plays in refrigerating media, wood treatment compounds, fire extinguishers and dust-laying preparations.

Epsom Salt, the sulphate of magnesium, is also of some importance in India, in the finishing of cotton fabrics, the dyeing of textiles and in the paper and leather trades, as well as in medicine. At one time upwards of 600 tons per annum were regularly imported, mainly from Germany, but it is now recovered from bitters and made from magnesite. The present production is about 3,500 to 4,000 tons per annum.

Dr M. S. Krishnan, in a recent paper, has summarized the magnesium resources of the State of Madras in which the largest deposits of the carbonate, magnesite, occur.

BERYLLIUM

Beryl, a silicate of beryllium and aluminium, $3\text{BeO} \cdot \text{Al}_2\text{O}_3 \cdot 6\text{SiO}_2$, is the only commercial source of the metal beryllium known today. Its precious varieties, the emerald and the aquamarine, are described under GEMS. Theoretically the mineral contains 14 per cent of beryllium oxide, or beryllia, and only 5 per cent of the metal, while in actual practice the amount extracted is considerably less than this. With a specific gravity of 1.84 the metal is but slightly heavier than magnesium (1.74) and considerably lighter than aluminium (2.7), but it possesses a much higher melting point than

either of these metals—1280° C., compared with 651° and 660° C.; moreover, it is harder and has a higher corrosion-resistance than either of them.

Beryllium is described as a brittle, steel-grey metal and hitherto its chief use has been in alloys with copper to which it imparts great strength after suitable heat-treatment. A copper alloy with 2.25 per cent of beryllium possesses six times the tensile strength of copper alone and has in addition a high fatigue-resistance. Such alloys are marketed as wires, rods and strips and are fabricated into springs of many kinds, gears, cams and bearing bushes, membrane discs of delicate instruments, watch and camera parts, valve guides, vibrating mechanisms and all manner of mechanical devices in which resilience, coupled with resistance to hard wear and fatigue, are essential. These alloys are also non-sparking and are used for tools, switch gear and other purposes in situations where fire hazards exist. Beryllium in small amounts greatly increases the tensile strength of nickel and it can also be alloyed with other metals, including aluminium, magnesium, iron, silver and platinum.

It is also employed in windows of X-ray tubes, and in conjunction with a compound of radium is a convenient source of neutrons for experimental work in nuclear physics. The development of atomic energy programmes in various countries has greatly increased the demand for beryllium, and it is of considerable potential importance as a moderator and sheathing metal for the uranium rods in slow neutron reactors. The metal is made on a commercial scale either by the electrolysis of chloride melts, or by the reduction of the fluoride with magnesium.

Some of the salts of beryllium such as the oxide, and the compound, zinc beryllium silicate, are used as coatings of the tubes used in fluorescent lamps, screens and electric signs. About 0.5 per cent of beryllium, added in the form of a soluble salt to the thorium-cerium solutions used for the impregnation of gas mantles, is said to strengthen the resulting body. Beryllium compounds are toxic and workers with them are liable to suffer from acute respiratory disorders unless suitable industrial health precautions are observed.

Ground beryl has been employed in the United States of America as a partial batch substitute for feldspar in the manufacture of electrical ceramic specialities, particularly of sparking-plug insulators. Beryllia itself is an excellent refractory, superior not only in this quality, but also in thermal conductivity and dielectric properties to alumina, especially at temperatures above 1900° C. when alumina softens, but its cost restricts its development and use.

The productive beryl deposits of India are found in the pegmatites associated with the granites of Rajasthan, but the mineral also occurs in the mica-bearing pegmatites of Bihar and Andhra, and is recoverable in small amounts as a by-product of mica mining, particularly from the Koderma Forest area of Hazaribagh and the

mica mines around Gudur in Nellore. Other localities are known, both in India and in Pakistan, and more will be found as the granitic tracts of the Peninsula and the Himalayas come to be mapped in detail.

K. L. Bhola described the Ajmer-Merwara occurrences in 1934; A. M. Heron contributed the Rajasthan deposits in 1938; H. Crookshank added his observations in 1948, while Dr M. S. Krishnan, the present Director of the Geological Survey of India, had reviewed the whole position in a special bulletin published in 1942 and reprinted in 1946. Although these Rajasthan pegmatites had provided material for generations of Jaipur lapidaries, their commercial exploitation did not really commence until 1930, and by 1932, 281 tons of beryl, valued at Rs 5,281, had been collected through the pioneer enterprise of Nusserwanji Contractor. This increased to 324 tons and Rs 7,261, in 1933, and then decreased again, so that the average annual production for the five years 1934-8 was but 67 tons, valued at Rs 3,984. The industry, by that time in a moribund condition, raised only 9 tons (Rs 900) in 1939, but war demands and better prices soon caused a revival—during 1940-2, a total of 171 tons was produced—and by 1943 output was 1,463 tons, valued at Rs 45,565. In 1944 and 1945 a total of 606 tons was won, and in 1946 exports were banned, all stocks of beryl in India were acquired by the Atomic Energy Commission, and the publication of statistics relating to the mineral ceased.

Beryl occurs sporadically as hexagonal or rounded crystals from half an inch to many feet in length, in wide pegmatite veins, generally where zoning is prominently developed and large quartz cores exist. Although most prevalent at the edges of these cores and in the feldspathic zones adjoining them, the mineral is also found in unzoned pegmatites of the coarse, granitic type. Shades of blue and green are its commonest colours, but it is a very deceptive mineral liable to assume other tints and is frequently mistaken for quartz, while a milky white variety is easily confused with feldspar and a black one with tourmaline. Most of the crystals are cloudy, but clear patches can sometimes be found suitable for the lapidary, though they are not in much demand. Giant crystals up to 20 feet in length and 4 feet in width, weighing upwards of 20 tons, have been seen and even larger ones reported to exist. Medium-sized crystals have been made use of locally as readymade gate-posts and built into the walls of castles, shrines and wells. Clean Rajasthan beryl generally contains over 12 per cent beryllia (BeO).

The mineral is won from eluvial deposits on the outcrops of the pegmatites, as well as from large quarries within them, which have been responsible for about half the output in the past, and as a by-product of mica mining to the extent of about 10 per cent. H. Crookshank believed that considerable quantities could be obtained from this source if the terms of the mining leases concerned were made more encouraging.

Owing to the capricious distribution of the mineral, mining had nowhere been continued deeper than the bases of exposed pockets; methods of working are primitive in the extreme and quarries were not opened unless many crystals each weighing 100 lb. or so could be seen. Small crystals, even if numerous, were considered worthless unless of gem quality. Considerable quantities of eluvial ore are still recoverable from ground already picked over, while large areas of Mewar, in Bhawat, are virgin ground as far as quarrying is concerned.

If beryl mining is to be firmly established in India not only will proper mining methods have to be adopted, but some system of concentration will have to be evolved, by which low-grade ores can be successfully treated and the valuable mineral separated from its gangue. It may then well be found that those pegmatites in which the mineral is 'well though thinly distributed' are more profitable sources of supply than the erratic, though rich, ore shoots roughly excavated in the past.

As the demand for beryllium in connexion with work on atomic energy projects has grown, so it has become increasingly difficult to obtain statistical information regarding beryl mining, as most countries now exercise strict control over exports and no longer publish figures of production. Some authorities give the world's output in 1940 as about 5,000 tons of beryl, but by 1944 it appears to have been nearer 3,000 tons, of which Brazil was responsible for some 40 per cent, and India for about 17 per cent; Australia was third on the list with 14 per cent, followed by Argentina with 11 per cent, the remainder coming from various parts of Africa. In later years supplies from South America are known to have declined while those from South Rhodesia and other States in South Africa have increased. There was an output of 490 tons in the United States of America in 1952 in an estimated world production of 6,500 tons. The Atomic Energy Commission for India offers rewards for new discoveries of beryllium ores.

LITHIUM

Lepidolite, or lithia mica, a hydrated fluo-silicate of aluminium, potassium and lithium, with a lithia (Li_2O) content ranging from 2 to 6 per cent, has long been known as a constituent of certain Indian mica-bearing pegmatites and vein granites. F. R. Mallet, in 1874, though not finding it widely distributed in such rocks in northern Hazaribagh, proved its existence in considerable quantities in some places, as, for example, in a dyke passing into a greisen near Pihra, where it occurs with cassiterite in irregular, scaly masses of violet-red to greyish violet and lead-grey tints. The former variety contained 3.71 per cent of lithia and 5 per cent of fluorine, the latter 1.75 per cent of lithia, 8.59 per cent of potash, 0.7 per cent of rubidium oxide and doubtful traces of caesium. About a

mile south of Manimundar in the same neighbourhood, the sides of a hillock are strewn with blocks of the mineral, one of which was estimated to weigh about 8 cwt.

In 1934, H. Crookshank found boulders of lepidolite near Mundaval, in Bastar, Madhya Pradesh, derived from a pegmatite some 30 feet in width, in which the mineral is confined to a zone of 15 feet in the centre. He estimated that this particular vein is capable of yielding several hundreds of tons of lepidolite containing 3.3 per cent of lithia and 4.8 per cent of fluorine.

Very large, deep lilac-coloured plates of lepidolite, up to six inches across, occur in a pegmatite vein at Sakangyi, Katha district, Burma, and it is probably to be found in some of the cassiterite-bearing greisens of Tenasserim in the same country.

Other important minerals containing lithium are spodumene, a silicate of lithium and aluminium, $\text{LiO}_2 \cdot \text{Al}_2\text{O}_3 \cdot 4\text{SiO}_2$, with 8.4 per cent of lithia and amblygonite, a fluo-phosphate of aluminium and lithium, $\text{AlPO}_4 \cdot \text{LiF}$, with 10.1 per cent of lithia. La Touche found a few lilac-coloured blocks of 'spodumene' in a valley close to the sapphire mines in Kashmir, but F. R. Mallet proved that some at least of the mineral was amblygonite. A green lithia-tourmaline and cookeite, a rare variety of lepidolite, also occur there, but the isolation of the locality would probably prevent the commercial extraction of the minerals, even if systematic prospecting proved their presence in large quantities. Spodumene analysing 5.8 per cent LiO_2 , and associated with some lithium-mica, has been recorded in the pegmatites of the Oregum mine in Mysore. All the minerals named are used as sources of lithium and its compounds, and it is also recovered in the form of lithium sodium phosphate from the brines of Searles Lake in California.

Lithium, with a specific gravity of 0.543, is the lightest of all the metals, weighing only 37 lb. per cubic foot, as against 109 lb. for magnesium, 167 lb. for aluminium and 450 lb. for cast iron, but it is soft enough to be cut with a knife and rapidly deteriorates through oxidation on exposure to the air. It is produced commercially by the electrolysis of its chloride, in the presence of potassium chloride, and is preserved in airtight containers after being coated with a light hydrocarbon oil.

It is an important degassing, deoxidizing and general purifying agent in metal refining, especially of copper and the bronzes. Very small quantities of lithium impart hardness, toughness and tensile strength to other metals and alloys and it is employed for this reason in extruded lead products, lead cable sheaths, copper electrodes and bearing metals. The *Bahnmetall* of the German metallurgists is a lead base alloy with only 0.04 per cent of lithium. Lepidolite is useful to the glass-maker for its fluxing, toughening and strengthening properties; in larger quantities it is an opacifier for both opal and white glasses. It is also employed in the manufacture of special porcelains and in glazes and enamels. Lithium chloride is a very

hygroscopic substance which finds application in air-drying plants; the chloride and the fluoride in fluxes for the electrical welding of the light metals; the hydroxide in alkaline accumulators; the hydride in the preparation of hydrogen; while other compounds have minor uses in pyrotechny, photography, mineral waters and pharmacy. The hydride has recently been suggested as a component of the hydrogen bomb.

Most of the lithium minerals are produced and consumed in the United States of America, the domestic production there rising from 113 tons in 1940 to 848 tons in 1944, expressed in terms of lithia content. Other producing countries include South-West Africa, Brazil, Argentina, Australia, Sweden and Germany. In 1948, exports of lepidolite from South-West Africa reached 2,266 tons compared with 2,535 tons in 1947.

CHAPTER VII

THE ATOMIC METALS AND THEIR ASSOCIATES

URANIUM

THE observations on uranium ores given below are based on information published officially before the second world war, in the course of which the development of atomic power from them was inaugurated. It is not permissible to discuss later developments but attention can be directed to the statement in Parliament, by the Minister for Natural Resources and Scientific Research, on 24 March 1951, that 'two uranium-bearing belts have recently been discovered in Eastern and Central India' and that a detailed examination of these areas was then in progress.

The earliest reference to a uranium mineral in India appeared in a German publication in 1860, in which Emil Stoehr recorded the occurrence of copper uranite ($\text{Cu}(\text{UO}_2)_2 \cdot (\text{PO}_4)_2 \cdot 8\text{H}_2\text{O}$), an old name for torbernite, a hydrated phosphate of uranium and copper, also known in Indian literature as 'uranium mica', at Lopsa Hill in Singhbhum. Many years later it was found again with uranium ochres as encrustations on magnetite-apatite rocks at Sungri, in Dhalbhum, associated with libethenite, a hydrated phosphate of copper.

Pitchblende or uraninite, the substance which started the development of atomic energy, a complex mineral with 69 to 91 per cent of uranium oxide, U_3O_8 , and the chief source of the metal, was first recognized in India by Sir Thomas Holland in 1901. It came from a mica mine, two miles south-east of Singar, in the Gaya district of Bihar, a locality examined by R. C. Burton in 1912. He found pitchblende in a wide pegmatite vein, mined for many years for mica, intrusive in mica schists, at Abraki Pahar. The mineral occurs as rounded nodules of all sizes up to a maximum of 36 lb. in weight, distributed in basic segregations in the pegmatite. Triplite, a phosphate and fluoride of iron and manganese, generally associated with large masses of ilmenite, usually forms the outer ring of these basic patches, though occasionally the pitchblende lies in the centre of feldspathic masses. White and yellow micas, tourmaline, zircon and torbernite also occur. The pitchblende is normally surrounded by a rim of uranium ochre. About 6 cwt of the mineral were recovered from this place during prospecting operations between 1913 and 1915.

Another locality lies five miles to the north-north-west, near Pichhli. Here, according to G. H. Tipper, the mode of occurrence

is much the same and small nodules of pitchblende, two inches or so in diameter, deeply altered into uranium ochres, are found, while bright green torbernite and lemon-yellow autunite also occur. The latter mineral has a similar chemical constitution to torbernite but with its copper replaced by calcium. Other accessory minerals include columbite, monazite, black tourmaline and pink garnet.

Pitchblende was found again about 1935 in a pegmatite quarried for beryl at Bisundi, Ajmer-Merwara. Nodules of the massive black mineral, with its typical pitch-like lustre, occur there in a kaolinized, laminated variety of albite feldspar known as cleve-landite. They are invariably surrounded by brightly coloured alteration products, the black or brownish kernel being followed by layers of scarlet or bright orange-red colours, passing outwards into gamboge and presumably composed of gummite, hydrated oxides of uranium and other bases of uncertain composition. The outermost crusts are formed of lemon-yellow, crystalline autunite.

A number of other minerals, niobates, tantalates and titanates of the rare earth elements frequently contain uranium and are sometimes referred to as its refractory ores. Indian examples include samarskite, fergusonite, euxenite and others, more fully described under TANTALUM and NIOBIUM.

According to Dr C. F. Davidson, Chief Geologist of the Atomic Energy Division, Geological Survey of Great Britain, well over a thousand localities are on record at which uranium-bearing pegmatites have been discovered, but not one has yet been found capable of yielding a significant tonnage of uranium minerals at an economic price, although many attempts have been made to work them in Tanganyika, Madagascar, Norway, the United States of America, Manchuria and elsewhere. Only where economics do not matter, or where production is possible as a by-product, is a small output of uranium ore likely to be practicable from such a source.

India's occurrences of pitchblende and other uranium-bearing minerals are of pegmatitic origin and unless mining costs are shared by some other product, such as mica or beryl, from the same vein, output from the pegmatites can only be small and fortuitous.

There is, however, another potential source of uranium in India, for commercial monazite concentrates commonly contain 0.3 to 0.4 per cent of U_3O_8 . Dr D. N. Wadia, Geological Adviser to the Government of India, in a publication dated 1949, mentions a content of about 0.3 per cent U_3O_8 adding, 'since considerable reserves of monazite sands exist (in association with the ilmenite sands of the west and east coasts), extraction of a notable quantity of uranium will be possible when the monazite sands are utilized for the manufacture of thorium metal'.

Uranium, the heaviest element occurring naturally, is described as a silvery white, malleable metal which burns easily in the air and is made by the reduction of its tetrafluoride with calcium in an

inert atmosphere. It is said to have four different atomic weights, namely 233, 234, 235 and 238, of which the last is by far the most abundant variety; uranium 235 which occurs with it being present in the ratio of only one part in one hundred and forty. These two varieties are isotopes and cannot be separated by chemical means; they can, however, be divided by physical processes.

Uranium is radioactive; its atomic nuclei undergo spontaneous and ceaseless disruption, emitting alpha, beta and gamma rays in the process, and giving birth by transmutation to a whole series of other elements including helium, radium, actinium and lead. The alpha rays are charged helium particles; beta rays consist of electrons, while gamma rays are described as very short electromagnetic rays of the same nature as X-rays but of more penetrating effect.

Until the discovery, in 1898, that pitchblende contained radium there was little demand for the uranium ores, a state of affairs that continued for some years afterwards, but as the demand increased, and in spite of the fact that there is only about one part of radium present in these ores for every three million parts of uranium, its unique properties made its extraction profitable and led to the exploitation of ore deposits in Colorado and Utah, United States of America, in the Belgian Congo and in Arctic Canada. Professor W. R. Jones has estimated that about 1932 the total weight of radium that had been extracted from uranium ores was less than one pound in weight, and that even by the end of 1942 all the world's supply would weigh little more than about 1,000 grams (2.2 lb.). He adds that about 85 per cent of this was employed for medicinal purposes, especially in the treatment of malignant diseases, and about 10 per cent in the preparation of luminous paints, generally consisting of zinc sulphide with minute amounts of radium, used for gun sights, aircraft instruments and so forth. Uranium and its salts in those days were by-products of the radium refineries and were not always saleable. The compounds found outlets to some extent in the manufacture of fluorescent glass, of an opalescent, yellow transparency but turning green by reflected light, in ceramic glazes, in photographic and analytical chemicals and as mordants in calico printing and dyeing. The metal had been tried in various alloys, as a deoxidizer of steel and as a catalyst in the fixation of nitrogen, but apparently without much success.

It was not until 1939, when the nucleus of the uranium atom was first split by bombardment with neutrons, with the freeing of more neutrons capable of developing further fissions, that the possibility of the chain reaction, 'the key to the release of atomic power on a large scale', was realized. 'The energy released from the fission of a pound of fissionable material is about that resulting from the explosion of eight thousand tons of T.N.T.', writes Professor Morrison, 'and it momentarily creates enormous pressures and temperatures of millions of degrees Centigrade.' (T.N.T., or

trinitrotoluene, is a high explosive adopted extensively for military purposes, particularly as a bursting charge in shells, bombs and mines.) Sir John Cockcroft, Director of the Atomic Energy Research Establishment in Great Britain, has stated that 'the complete destruction [by fission] of one ton of uranium releases as much energy as the burning of three million tons of coal'.

Thus uranium from being little more than a chemical curiosity has become the most eventful metal in the world and statistics of the production of its ores are now jealously guarded secrets in the countries concerned. It is required for the separation of its isotope, uranium 235, and for the preparation of plutonium, another powerful atomic fuel, and used, like uranium 235, in atom bombs.

Atomic energy is liberated under controlled conditions in nuclear reactors, or piles, in which chain reactions are allowed to develop in natural uranium, embedded in moderators such as graphite which have the power of slowing down neutrons. These piles are used for research purposes and to investigate the effects of intense radiation on the properties of materials. In less than a decade uranium has been responsible for the creation of vast new industries involving enormous expenditure and employing many thousands of workers. For accounts of the processes employed the reader is referred to the official account in *Britain's Atomic Factories*, published in 1954 and dealing with the design, construction and organization of the headquarters at Risley in Lancashire, and the three large operating units which produce uranium from its ores at Springfield in Lancashire, plutonium at Windscale in Cumberland and uranium 235 at Capenhurst in Cheshire. A companion publication is entitled *Harwell: the British Atomic Energy Research Establishment* (1952).

Though most of the work done in the atomic factories of the world to date has been to direct this new source of power into weapons of destruction, to quote the words of the British Minister of Supply in December, 1953: 'At the same time impressive progress has been made in applying the forces of nuclear fission to peaceful and constructive uses, thus opening up to this and future generations an ever-expanding prospect of material betterment.'

The most striking development in this direction is the proposed construction of large 'fast reactors', which use no moderators, can be used as sources of power and in which at the same time, there are prospects that more secondary fuel in the form of plutonium can be bred than the amount of primary fuel, uranium 235, consumed in the process. The first experimental, power-producing, fast-breeder reactor of this type has been operating in the United States of America since early 1953. In the same country a large submarine to be driven by atomic power has already been launched. In January 1953, an extensive programme was adopted in England to include the immediate building of a reactor to produce power and of a full-scale breeder reactor, the combined objective

being set at 50,000 kilowatts. In June 1954, the British Electricity Authority announced its belief that a significant contribution will become available to the nation's power supplies from nuclear energy stations within the next 20 years, and its hope soon to begin the construction of such stations as part of its normal activities.

Though the primary object of large nuclear reactors so far operating in the world has been the transmutation of uranium into plutonium, radioactive isotopes of many elements are also being made on a large scale and there is now an extensive chemical industry engaged in the transmutation of one element into another. Mention must also be made of the new synthetic transuranic elements such as neptunium, americum and others formed by secondary reactions in atomic piles. Radioactive isotopes are increasingly used in industry, biochemistry and medicine. Among many other applications they can be used as 'tracers' in animals and plants, for the detection of air and gas leaks, to measure the wear of bearings, for the examination of metal castings and for the dispersal of static electrical charges in textile mills and other manufacturing processes. Cobalt 60, made in the atomic pile, is an efficient substitute for radium in conventional therapy, but while radium still costs the equivalent of over Rs 66,000 per gram, cobalt 60 of equivalent activity costs about Rs 260 for the same quantity.

At the official opening of the monazite processing factory of the Rare Earths Ltd, near Alwaye, in Travancore-Cochin, on 24 December 1952, by Pandit Jawaharlal Nehru, the Prime Minister stated that the plan drawn up by the Atomic Energy Commission for the development of atomic energy in India had been approved by the Government of India. This plan provides for the construction of a medium-sized reactor in India within the next three years.

Ores of uranium and other radioactive minerals in India are under the control of the Atomic Energy Commission and rewards are offered for the discovery of new deposits, with grants-in-aid for mining developments.

THORIUM

Monazite, the principal ore of thorium, is a monoclinic phosphate of cerium and other rare earth metals, including lanthanum, praseodymium, neodymium and samarium, $\text{Ce}(\text{La}, \text{Pr}, \text{Nd}, \text{Sm})\text{PO}_4$, with small amounts of the rare earth elements of the terbium and yttrium groups, in addition to thorium and, occasionally, uranium. It also contains minute quantities of radium and mesothorium. The thoria content may vary from nothing to as high as 33 per cent, and that of urania from nil to 4.5 per cent. Travancore monazite varies in thoria content from about 8 to 10.5 per cent: Ceylon material averages about 10 per cent.

In its original situations monazite is found in pegmatites, as in the prismatic crystals, associated with pitchblende and columbite,

near Pichhli, Gaya district, Bihar; in similar rocks in the vicinity of Bangalore, Mysore; or, again, in small grains in pegmatites traversing the gneisses of south Travancore, and in parts of Ceylon, where it is also a constituent of biotite and hornblende granites and of gneisses. A new member of the monazite group was described in 1953 as 'cheralite' (from *Chera* the ancient name of Travancore). It is a dark green mineral found sparingly in brittle masses with black tourmaline, small greenish yellow chrysoberyls, partly metamict dark zircon and much smoky quartz, in a kaolinized pegmatite at Kuttakushi, Kalkulam taluk, about 25 miles east-south-east of Trivandrum. Similar material was collected from Cootykad Pothay in the adjoining Vilavancod taluk by E. Masillamani about 1914. Almost all monazite contains some thorium and a little uranium replacing the cerium-lanthanum earths in the crystal lattice of the mineral, but in cheralite, with 29.45 per cent of thorium and 6.56 of uranium, this substitution has been carried far beyond normal quantities. We wish to thank Messrs Bowie and Horne of the Geological Survey of Great Britain for giving us this information preparatory to its publication. Cheralite does not occur in sufficient quantities to be of any economic importance. Dr D. N. Wadia, in 1952, gave the provisional name 'travancorite' to a mineral rich in thorium and uranium called green monazite from Travancore.

Monazite deposits of commercial importance are generally confined to the sands of sea beaches; the mineral has a high enough specific gravity, sufficient hardness and chemical stability, to permit of its transport there after its liberation from its parent rocks by weathering agencies, accompanied by its constant associates ilmenite, arizonite and magnetite, garnet, zircon and rutile. Its combination of suitable properties is also responsible for its concentration, with its companion minerals, in favourable locations on the beaches where wave action can bring its sluicing effects into play, and the bulk of the lighter minerals is removed by tidal currents.

In such natural, coastal concentrates the monazite exists as small, rounded, translucent grains of an amber-yellow colour, averaging 0.1 to 0.2 mm. in diameter. Twenty-five years ago, Sir Edwin Pascoe gave the average percentage of monazite in the Travancore beach sands as about 10 per cent, yet today, it is stated by Dr C. F. Davidson, Chief Geologist to the Atomic Energy Division, Geological Survey of Great Britain, that 'probably no beach deposit workable on a large scale, can yield ore with more than about three per cent'. Old sand dunes near the coast sometimes carry monazite and such wind-borne deposits are occasionally cemented into compact masses by infiltrated carbonate of lime. In older strata still, such as the Warkalli Beds, there are, according to G. H. Tipper, dark brown, ferruginous grits composed of the same minerals as those of the existing beaches with monazite in some quantity.

The monazite sands lying between Cape Comorin and Quilon were discovered in 1909 by G. W. Schornberg, and eventually five major deposits were located at Liparam, Pudur, Kovilam, Varkala (Warkalli) and Nindikari, respectively. Fuller descriptions of them will be found under TITANIUM. Their exploitation commenced in 1911 and from that date until the end of 1944, 51,211 tons had been produced. Their site values are not given, owing to their great variations, which in any case probably bore little relation to the value of the mineral in the world's markets at the time. The record year was in 1938 with its output of 5,221 tons, valued at Rs 2,33,700, and after 1944, ordinary trade exports and the publication of statistics relating to them have ceased for strategic reasons. Dr D. N. Wadia stated, however, in 1949 that output had risen progressively to 5,000 tons per annum, while Dr W. D. West, Director of the Geological Survey of India at that time, had, in 1945, given the reserves of the Travancore beaches alone at over two million tons. The firms engaged in monazite winning are Travancore Minerals Ltd, Hopkins and Williams (Travancore) Ltd, F. X. Pereira & Sons Ltd, and The Associated Minerals Co. Ltd, acting as agents of the State which took over the control of the deposits in 1946. A factory capable of processing 1,500 tons of monazite per annum has been built at a cost of about Rs 80 lakhs at Alwaye, by Indian Rare Earths Ltd, a company financed jointly by the Government of India and the Government of Travancore-Cochin.

Before 1911, the world's supplies of monazite were almost entirely derived from Brazil, but India obtained the lead in 1914 and probably kept it until the decline in the demand supervened as a result of the spread of electricity for lighting purposes, and reduced output to a fraction of its former figures. For the years 1911 to 1915 inclusive, Indian production was fairly steady at about 1,000 tons per annum. It then rose rapidly and passed a peak of 2,118 tons, valued at Rs 8,82,285, in 1918. A severe fall took place in 1922, and the average annual production over the decade ending 1931 only amounted to 172.5 tons. The export of the sand was suspended in 1929 and 1930, but in 1932 production had increased to 654.3 tons and to 1,009 tons in 1934. The decade from 1934 to 1943 witnessed the greatest activity in the monazite industry, the average annual production over the ten years concerned being 3,090 tons. In 1938, the world's production of monazite was 5,926 tons, of which India supplied 88 per cent, the Netherlands East Indies 6.5 per cent and Brazil 5.5 per cent. Of 19,204 tons of monazite imported into the United States of America, over the 4 years 1939 to 1943, three-quarters came from India and one quarter from Brazil.

With the growth of electric lighting thorium lost much of its earlier industrial importance, for its nitrate, made from monazite, was used in the manufacture of incandescent gas mantles as it

yields the oxide, thorium, on heating. At the same time this outlet has not entirely ceased for such mantles are still utilized on a large scale in petrol and paraffin-burning lamps, particularly in India and China. Thorium, a heavy white powder, is one of the most refractory substances known, with its melting point of $3050^{\circ}\text{C}.$, and is employed in the manufacture of special refractories, such as crucibles for the laboratory melting of vanadium and titanium. It is also added to tungsten, intended for use in lamp filaments, as it inhibits excessive crystal growth and so improves the mechanical properties of the wire at the incandescent temperatures to which it is subjected. Thorium, in the proportion of five parts per hundred parts of cobalt, is used as an activator in the mixed catalysts for the Fischer-Tropsch synthesis of hydrocarbons. It is also an important constituent of optical glasses for special photographic lenses, as described under CERIUM. Another application of thorium is in electron-emissive elements and it is used too as an anode coating in special types of radio bulbs.

In recent years the metal has assumed a new role for it is a radioactive element and a potential source of atomic energy. Just as uranium in the course of its atomic disintegration produces a new series of daughter elements, so thorium gives rise to a closely parallel one: in the same way as natural uranium ($\text{U } 238$) can by capture of a neutron be changed into plutonium, so thorium with its atomic weight 232 can be transmuted in a nuclear reactor into uranium 233, an isotope which is said to possess properties similar to those of uranium 235 and plutonium. It has been described by Sir John Cockcroft as an alternative secondary nuclear fuel, and one of the problems facing the metallurgist today is the preparation of thorium metal in a form suitable for use in reactors.

Thorium, described as a very ductile, soft, lead-like metal, can be obtained by the reduction of its oxide with calcium and calcium chloride in an inert atmosphere. The powder so obtained is compacted, sintered and processed generally in a similar manner to that adopted in the case of tungsten. It is available on the market in ingot and sheet form containing about 98 per cent thorium. The commercial salts of thorium include the oxide, ThO_2 , in which the rare earth metals and iron are absent; the hydroxide $\text{Th}(\text{OH})_4$, about 99 per cent pure; the sulphate, $\text{Th}(\text{SO}_4)_2 \cdot 9\text{H}_2\text{O}$ and two forms of the nitrate, $\text{Th}(\text{NO}_3)_4 \cdot 12\text{H}_2\text{O}$ and $\text{Th}(\text{NO}_3)_4 \cdot 4\text{H}_2\text{O}$. The latter grade contains about 6 per cent of the sulphate and is the variety used in the manufacture of gas mantles.

The radioactive substance mesothorium is a natural disintegration product of thorium and is recovered as a by-product in the course of thorium nitrate manufacture. One ton of monazite containing 5 per cent of thorium is said to yield about 3 milligrams of mesothorium. It has a half-life of but $5\frac{1}{2}$ years and was used as a substitute for radium in the treatment of malignant diseases and in the preparation of luminous materials.

Other thorium-bearing minerals include the oxide thorianite, ThO_2 , and the silicate, thorite ($\text{ThO}_2 \cdot \text{SiO}_2$). Thorianite is an end member of an isomorphous series of mixed cubic minerals, the other end member of which is an oxide of uranium. A black cubic mineral from Thadagay Hill, Travancore, with the high specific gravity of 10.3, which contains 32.3 per cent thorium and 39.6 per cent uranium oxide, may be uranothorite, a member of this series. Both thorianite and thorite are known from Ceylon and there can be little doubt that sooner or later they will also be found in southern India.

In prospecting for radioactive minerals with the Geiger counter, it should be remembered that the instrument does not distinguish between radiation due to uranium and that due to thorium minerals, though the gamma emission of the thorium series is less intense than that due to the uranium series.

Inquiries from Dr Davidson of the Atomic Energy Division, Geological Survey of Great Britain, in February 1951, to whom we wish to express our indebtedness, confirmed the fact that the demand for thorium in British atomic energy developments is still limited to experimental quantities. The United States Atomic Energy Commission is interested almost wholly in uranium. It is a reasonable assumption that the capital invested in uranium plant is now so enormous that a change-over to thorium is highly unlikely, so long as adequate supplies of uranium are available, and there is no foreseeable prospect of a shortage of this element as new sources of supply are continually being developed. In this connexion it is as well to remember that uranium is not a particularly uncommon constituent of the earth's crust, being about one-twelfth as abundant as lead and twenty times as abundant as silver. Many problems remain, however, connected with its concentration and profitable recovery from very low-grade ores.

Since 1951, however, more attention has probably been directed to thorium as knowledge of fast reactors (see URANIUM) has grown and their construction been undertaken. This depends on the proposals made by some authorities to use thorium as a blanket around the cores of such reactors and its own transmutation into uranium 233 in the process. The latter is described as an alpha-active, fissile isotope and as good a nuclear fuel as uranium 235 or plutonium 239. It may well be, therefore, that as more breeder and power reactors come to be built that the demand for thorium (and for monazite its parent mineral) will increase. It should be added that natural uranium can also be used as a blanket around the cores of plutonium or of uranium 235 mixed with uranium 238. Looking farther ahead, we have to thank Dr R. Spence, Director of the Chemical Laboratories of the British Atomic Energy Research Establishment at Harwell, for permission to quote his view that 'the long-term future of atomic energy as at present conceived depends on the successful transmutation on an industrial

scale of natural thorium into the fissionable uranium 233 and of natural uranium into plutonium¹.

CERIUM AND THE RARE EARTH METALS

There are some 17 elements grouped under the term 'rare earths', so called in the past on account of the scarcity of their natural compounds at that time and the general resemblance of their oxides to lime and magnesia. The rare earths are similar to one another in many respects, are always found together, are often associated with uranium and thorium and are only separately isolated with extreme difficulty, so much so that practically not one of them has yet been prepared in a state of high purity. It should be stated that in the latest classifications the three elements scandium (originally found in the mineral euxenite), yttrium and lanthanum, are no longer definitely grouped with the rare earth elements, though their properties are very closely related and they occur in nature together. In this note the older system is followed. Though found sparingly in many mineral species, monazite, the orthophosphate of the cerium elements with thorium, is their only important ore. Its distribution and economics are considered under TITANIUM and THORIUM, and it remains to describe briefly the applications of such members of the earths as find places in industry today.

They are divided arbitrarily into the three groups of the cerium, terbium and yttrium earths between each of which there are no sharp distinctions. Ceylon monazite averages about 27 per cent of ceria, 30 per cent of lanthana and the allied oxides, and 2.5 per cent of the yttria and terbia earths: there is no reason to suppose that the Travancore mineral differs greatly from this composition.

The cerium group, the only one of practical importance at present, includes, besides cerium itself, lanthanum, praseodymium, neodymium, and samarium. An analysis of a typical monazite sand, quoted by H. E. Kremers, shows thoria 6.5 per cent, ceria 28.8, lanthana etc. 31.8, yttria etc. 0.32, terbia etc. 0.8 and urania 0.2 per cent. The 31.8 per cent of the lanthana earths are distributed in the following proportions: lanthanum oxide (La_2O_3) 15.6 per cent, neodymium oxide (Nd_2O_3) 11.4 per cent, praseodymium oxide (Pr_2O_{11}) 3.6 per cent and samarium oxide (Sm_2O_3) 1.2 per cent. Commercial metallic cerium may contain the metals in the following proportions: cerium 45 to 50, lanthanum 20 to 25, neodymium and praseodymium 15 to 20, and samarium 5 to 10 per cent, with small amounts of iron. They are so closely related and the separation of their salts by repeated fractional crystallizations is so tedious a process that for most industrial uses a mixture of them all is considered suitable.

This alloy, often referred to by its German name of *Mischmetall*, is prepared by the electrolysis of the rare earth chlorides with the chlorides of calcium, magnesium and sodium as fluxes. The crude

product is remelted under molten fluxes, with alloying additions, and then cast into grooved steel moulds to form the rods which, cut into suitable lengths, form the familiar but misnamed 'flints' of mechanical lighters, the pyrophoric alloys that emit sparks when struck with an abrasive substance. Most of them are alloys of the rare earth metals with iron contents varying from 15 to 25 per cent, with small quantities of zinc, magnesium, copper or aluminium. Cerium itself is a soft and ductile metal and the addition of iron is necessary to increase both hardness and brittleness in the finished product. Alloys of these types have been employed as tips to tracer shells and bullets which, igniting as the projectile is fired, enable its path through the air to be traced. Ferro-cerium has been tried as a scavenging agent for the removal of oxygen and other unwanted impurities from cast iron. Small amounts of cerium are constituents of certain aluminium and magnesium alloys, and the metal is also used in the evacuation of radio bulbs. The applications mentioned are said to account for about one quarter of the monazite derivatives.

About half the total production of cerium salts, however, is said to be consumed in the cores of arc carbons, as they increase the luminosity of searchlights, cinema projectors, therapeutic lamps, etc., and at the same time act as stabilizers and smooth out fluctuations in lighting intensity.

We have to thank Messrs Thorium Ltd for much of the following information on the chemical compounds manufactured from monazite. They are marketed either as 'pure' salts of cerium, lanthanum, samarium and thorium, in which contamination by the other elements is kept below certain definite limits, in the case of cerium itself not more than 0.1 per cent of the other earths of the group, and in some cases not more than 0.05; or as 'technical' rare earth compounds which contain varying proportions of the other elements as well as cerium, 'didymium', neodymium and yttrium, as the case may be. The applications of cerium salts include their uses in volumetric chemical analysis as oxidizing agents; in the preparation of organic compounds such as aldehydes and quinones; as waterproofing and fungicidal agents for textiles and leather; as catalysts, for example in the manufacture of acetone from acetylene; as commencing materials in the manufacture of resins, naphthenates, etc., for paint driers; as constituents of magnesium flashlight powders, and in medicine for the prevention of sickness. The glass-maker uses cerium salts both as decolorizing agents and in the production of yellow glasses, as well as opacifiers for vitreous enamels. Finally, apart from their use in arc-lamp carbons already referred to, the average gas mantle contains about 1 per cent of ceric oxide.

A number of pure lanthanum salts made from monazite are marketed, including the acetate; the double lanthanum ammonium nitrate, with not more than 0.02 per cent of cerium, and in which

neodymium and praseodymium are practically absent; the chloride, suitable for the electrolytic preparation of the pure metal, and the oxide, a constituent of special optical glasses. Samarium oxide, containing about 99.0 per cent of Sm_2O_3 , is yet another derivative of monazite which finds its uses in fluorescent tube lighting.

Commercial didymium compounds include the carbonate with 0.6 per cent ceria, as well as the chloride, a suitable material for the preparation of resins for paint driers, the nitrate and the oxide, from which special coloured glasses both for decoration and for the use of welders as spectacle lenses are made. The pink neodymium oxide is also available and is 87 per cent pure. It is an excellent glass decolorizer and a source of other neodymium salts. Another ceria-enriched, rare earth oxide mixture is prepared with special attention to its physical properties for polishing high-grade optical glass. It is faster in effect and cleaner in handling than rouge.

Many of the rare earth elements yield sharp and narrow absorption bands in the visible and ultra-violet parts of the spectrum, a characteristic property taken advantage of by prospectors in the field, as a confirmatory test for monazite which displays well-marked didymium bands in the yellow, green and blue sections.

The following account of the uses of certain rare earths in the glass industry is based on information kindly supplied by Messrs Chance Brothers Ltd. Both lanthanum and thorium oxides are used in optical glasses which have been developed in recent years, their effect being to produce a glass with a high refractive index coupled with a low dispersion. These properties are desirable from the point of view of correcting photographic lenses, and are normally obtained by the use of barium which gives a series of glasses known as the dense barium crowns. Lanthanum and thorium oxides, however, have the advantage that the refractive index is increased relative to that of the barium glasses. Typical compositions of these new glasses are as follows:

		per cent	per cent	per cent	per cent
SiO_2	.. ..	21.5	10.3	15.0	11.3
BaO}	.. ..	45.0	26.9	31.3	14.7
PbO}	.. ..	..	..	9.0	12.7
B_2O_3	.. ..	19.0	24.8	15.4	19.5
La_2O_3	.. ..	..	18.4	13.0	18.0
ThO_2	.. ..	14.5	13.5	11.3	13.3
ZnO}	.. ..	..	4.0	2.5	3.1
ZrO_2	.. ..	..	2.1	2.5	7.5
Nd	.. ..	1.650	1.691	1.717	1.744
V	.. ..	58.5	54.8	47.7	44.7

Nd is the refractive index for the helium D line.

V is the reciprocal dispersive power.

Cerium oxide in glass has the property of absorbing ultra-violet light and use is made of it in the so-called Haze Filter, employed

TONS

5500

5000

4500

4000

3500

3000

2500

2000

1500

1000

500

0

1910

1915

1920

1925

1930

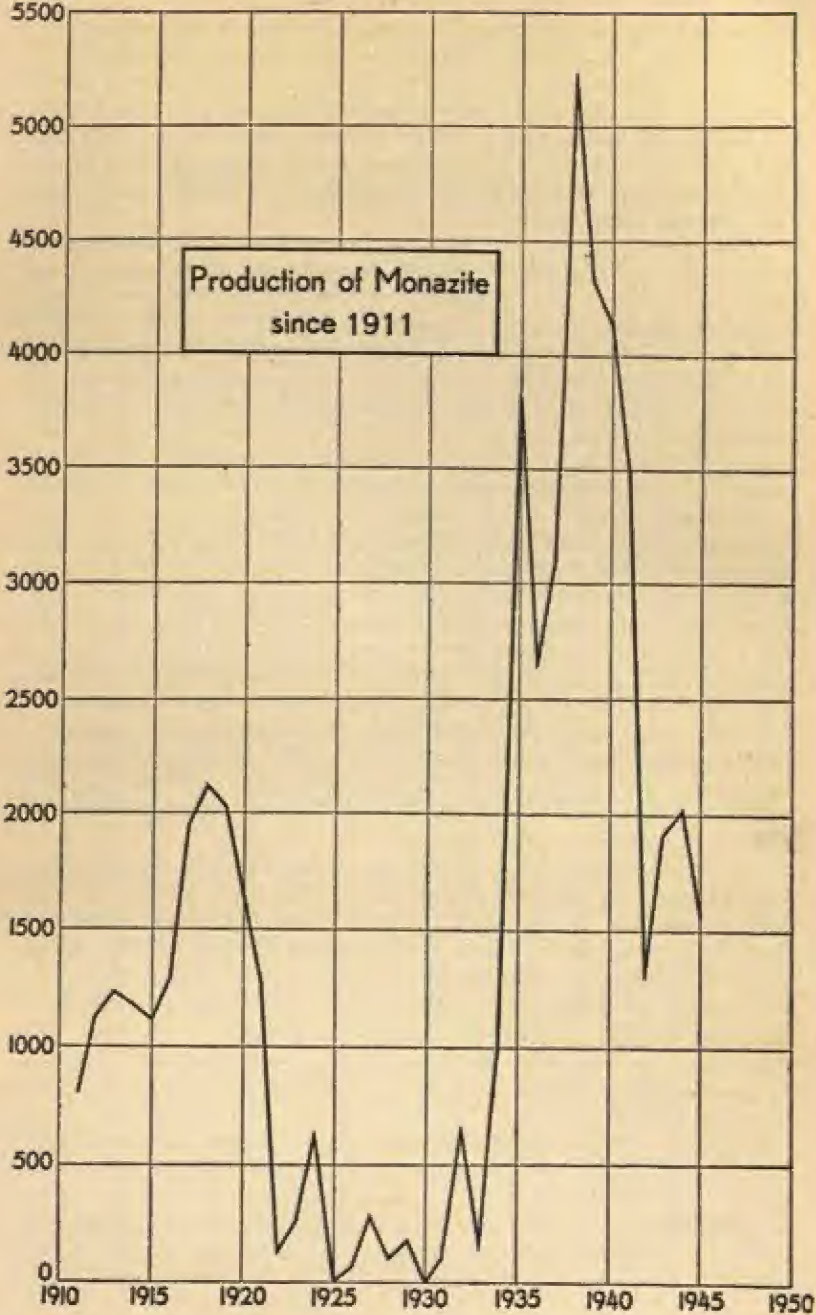
1935

1940

1945

1950

Production of Monazite
since 1911



in photography for absorbing the ultra-violet light which is scattered by atmospheric haze. Both didymium and cerium oxides are constituents of didymium filter glass, which not only absorbs ultra-violet light, but also possesses an absorption band corresponding to the sodium D band, and is for this reason used in the manufacture of spectacle lenses for glass-blowers and others exposed to the glare of sodium excitation. The well-known Crookes' lenses also contain both these oxides.

The other groups of the rare earths are not yet utilized industrially; that trifling amounts of yttria and erbia were at one time employed among other rare earths in the glowers of Nernst lamps, before the introduction of the tungsten filament lamp, is merely a matter of historical interest. Inquiries in London in 1951 elicited the information that only a few pounds of the yttria earths are sold annually, mainly to scientific institutions for research purposes. Commercial yttrium oxide is a light fawn-coloured powder containing 80 per cent of yttria and 15 per cent of other rare earth oxides. The remaining 5 per cent is represented by loss on ignition.

Besides occurring in monazite, yttrium and its associates, lutetium, ytterbium, thulium, erbium and holmium are found in a number of other minerals, including samarskite and fergusonite, niobates and tantalates of yttrium, cerium and uranium, already mentioned under NIOBIUM and TANTALUM. More important from the yttrium point of view, however, are xenotime, its natural phosphate, $Y_2O_3 \cdot P_2O_5$, and gadolinite, a silicate of yttrium, beryllium and iron $FeO \cdot 2BeO \cdot Y_2O_3 \cdot 2SiO_2$. A mineral related to xenotime has been found in the apatite deposits of Kanyaluka, in Singbhum, and it contains yttria and the related earths 47.6 per cent, ceria earths 5.8 per cent and thoria 6.92 per cent. Gadolinite was discovered in 1903, by Baidyanath Saha, in a tourmaline pegmatite at Hosainpura, Palanpur, Bombay.

The vicissitudes of the Indian monazite trade furnish excellent examples of how mineral products which, having become of little consequence for their primary purposes, are needed once more as fresh uses are found for them; and, again, of the manner in which apparently worthless by-products of an earlier period may later become the mainstay of a mineral industry. Such may again be the case, for the production of larger quantities of the individual rare earth metals in a pure condition, would, as the eminent American metallurgist, W. J. Kroll, has stated, undoubtedly yield unexpected results.

India's monazite sand deposits are the largest in the world; in quality and thoria content they easily come first; but these are not reasons why reconnoitring for new deposits, or for the extensions of existing ones, should not be energetically prosecuted, for they are national assets of great strategic and economic importance.

CHAPTER VIII

THE RARER ELEMENTS OF INDUSTRIAL IMPORTANCE

ANTIMONY

STIBNITE, or antimonite, the natural trisulphide of antimony, Sb_2S_3 , with 71.8 per cent of the metal, occurs in quartz veins traversing slates of Palaeozoic age, near Krinj and Partson, about 13 miles from Chitral, in Pakistan, in a mineralized zone which, according to V. P. Sondhi, extends for several miles. S. Tayyab Ali, of the Geological Survey of Pakistan, later reported deposits $3\frac{1}{2}$ miles south-west and 5 miles west of Krinj, in the Owiret and Monia areas. Mining was started in 1939, at first in haphazard fashion, but regular exploitation commenced in 1942, by the Parekh Varani Syndicate and later by the Chitral Mining Corporation of Bombay, only to cease after partition in 1947. Before dispatch to the Star Metal Refinery at Vikhroli, near Bombay, high- and low-grade ores were blended at the mines so as to give an average of 35 to 40 per cent of antimony in each batch. Experiments by the Utilization Branch of the Geological Survey of India have proved that the run-of-mine ores, containing some 16 per cent of antimony, are readily amenable to beneficiation by tabling and froth flotation, yielding a concentrate containing over 93 per cent of stibnite. Zinckenite, the double sulphide of lead and antimony, $\text{PbS.Sb}_2\text{S}_3$, is reported to occur, while jamesonite, a related mineral, $2\text{PbS.Sb}_2\text{S}_3$, was identified by G. H. Tipper, from Awi, near Shogar, a few miles from Krinj. The development of these deposits is handicapped by their location at an elevation of about 8,000 feet in an inaccessible region, and by the long lead to Dargai, the nearest rail-head. From other parts of Pakistan old antimony mines are reported to exist in the Zaimukht Hills, north of Thal, in the Kurram valley, and, with lead ores, at Sekran, near Khuzdar in Kalat.

The existence of antimony ores near the Shigri glacier in Lahul, East Punjab, has been known for upwards of a century, and a consignment of 15 tons of stibnite from this locality reached England in 1905. The lodes are thick, contain stibnite with its decomposition products, cervantite, $\text{Sb}_2\text{O}_3.\text{Sb}_2\text{O}_3$, and kermesite, $2\text{Sb}_2\text{S}_3.\text{Sb}_2\text{O}_3$, occur in gneissose granite and are associated with argentiferous galena, zinc blende, pyrite and manganoferous siderite. It is reported that some of the stibnite contains small amounts of gold. The inaccessibility of the neighbourhood, its elevation of 13,500 feet beyond the Hamta pass (14,500 feet), and its climate, which is

rigorous enough to limit work to two or three months in the year, have hindered any active exploitation up to the present time.

The stibnite deposits of Thabyu, in the extreme south-east of the Amherst district of Lower Burma, are close to the Thailand frontier. A. M. Heron states that the veins are very large, the biggest measured being at least 20 feet thick and traceable for 600 feet. The ore consists of radiating or parallel crystals, or massive aggregates of stibnite, superficially oxidized to cervantite and stibiconite, $H_2Sb_2O_5$. The vein stuff is a calcareous chert showing distinct brecciation and often a cellular structure. The country rocks are black, fissile slates of unknown age. Small angular fragments of slate occur in the veins, which are believed to fill tension cracks, and to have been deposited during periods of upheaval, at moderate depths, from solutions at comparatively low temperatures. During times when high prices have ruled in the markets for metallic antimony, large quantities of ore have been obtained from Thabyu and other places in the Amherst district. Thus, in 1916, they supplied upwards of 1,000 tons, but in more normal years the distance of the deposits from any modern ways of transportation renders their working unprofitable. According to the Mining and Mineral Production Reports of the Government of Burma, 101 tons of antimony ore were produced in 1949, falling to 54 tons in 1950, and rising again to 286 tons in 1951.

A narrow quartz vein containing stibnite has been traced for 600 or 700 feet, in the slates forming the crest of a low ridge, on the western slopes of the eastern of the two parallel ranges of the Thaton-Martaban hills, seven miles to the east of Katun railway station, in the Thaton district of Lower Burma, which adjoins the Amherst district on the north.

The stibnite deposits of the Southern Shan States were examined by H. G. Jones, who concluded that none of them appear to be large or of much economic importance. They occur at the following localities: Naking and Loi Hke in Mong Hsu, Mong Ing in Kengtung, Hkomhpok and Loi Hsang in Mong Kung. The stibnite usually exists in a bladed, striated variety and more rarely in drusy and massive forms. The oxidized ores cervantite and valentinite, Sb_2O_3 , are common. The Naking deposit, from which about 1,000 tons of ore were taken in 1908, consists of stibnite irregularly deposited through a vein in sandstone, perhaps of Jurassic age. Some of the others appear to be quartz-stibnite veins in Plateau Limestone.

Small quantities of stibnite and antimony ochre have been won from veins and patches in the quartzose rock of a schist series at Chikkannanahalli, in the Chitaldrug district of Mysore. The veins are about two inches in thickness, swelling in places to wider lenses up to a foot or so in width. Prospecting operations have shown that the grade of the orebody would have to improve considerably before mining under normal conditions could be entertained.

Antimonial lead was produced as a by-product at the Nam Tu smelters of the Burma Corporation until the Japanese invasion of the country stopped their operations. During the first world war the requirements of the Indian Ordnance Department were met from this source, and large quantities were exported to the United States of America after that time. Official statistics only commenced in 1924, and from that year until the end of 1941, 21,617 tons had been made. Up to about 1933 the composition of the product used to vary between the following limits: lead 72 to 77 per cent, antimony 21 to 24 per cent and 6 to 8 oz. of silver to the ton. From 1934 onwards it was more consistent, with lead about 81.75 per cent, antimony 17.75, copper 0.22 and 3 to 4 oz. of silver per ton. It is estimated that over 4,000 tons of metallic antimony were contained in the total product. The run-of-mill ore at Nam Tu sometimes averaged over 1 per cent of antimony and it was doubtless derived from the presence of one or more of the following minerals, all of which have been identified in the lead-copper-silver-zinc ores of Bawdwin: boulangerite, a sulphantimonite of lead, $5\text{PbS} \cdot 2\text{Sb}_2\text{S}_3$; bournonite, a sulphantimonite of lead and copper, $3(\text{Pb}, \text{Cu})\text{S} \cdot \text{Sb}_2\text{S}_3$; pyrrargyrite, a sulphantimonite of silver $3\text{Ag}_2\text{S} \cdot \text{Sb}_2\text{S}_3$, and tetrahedrite, a sulphantimonite of copper $4\text{Cu}_2\text{S} \cdot \text{Sb}_2\text{S}_3$.

Antimony is too brittle a metal to be used alone, but it has many important alloys, particularly with lead and tin. To the former it imparts hardness and tenacity, and such 'hard lead', with from 5 to 12 per cent of antimony, is used in the grids of storage batteries. Other alloys of the same type find applications in the chemical industry in acid storage tanks, pumps and valves; in shrapnel bullets and the fillings of small-arms ammunition; in the sheathings of telegraph and telephone cables; in certain alloys used for collapsible tubes and foils, as well as for many architectural and ornamental purposes for which lead alone is too soft.

Metallic antimony is an essential component of most of the 'anti-friction', 'white' or 'bearing-metals', which also contain tin or lead. 'Babbitt metal', for instance, contains 83 to 89 per cent tin, 7 to 11 per cent antimony and 4 to 6 per cent copper. The lead base alloys may contain up to 15 per cent antimony. The type metals of the printer are essentially alloys of lead (50 to 80 per cent), with varying amounts of antimony (up to 30 per cent), in which small percentages of tin, bismuth and copper may also be incorporated. They are characterized by their fusibility and power of slight expansion on solidification. The Britannia metals, which by reason of their silvery appearance are employed in the manufacture of table-ware, are alloys of tin or lead and antimony in varying amounts, with smaller quantities of copper and zinc. Pewter is a related alloy of tin, lead and antimony.

Compounds of the metal have widely spread applications. *Surma* is the vernacular name for the powdered natural sulphide, sold in the bazaars of northern India and Pakistan as a cosmetic

for the beautifying of the eyes and eyelashes. The more prosaic services of the sulphide include its use as a dark pigment in camouflage paints; it is said to possess the same infra-red reflecting power as green foliage. Incorporated in the charges of shells it produces a dense white smoke when they explode, a property which it shares with the oxide. The red trisulphide, or Antimony Red, is a useful pigment, and both it and the pentasulphide are employed in the vulcanization of rubber. Many of the compositions of the heads of safety matches contain about 3 per cent of antimony trisulphide, while the striking surfaces of the box itself contain about 8 per cent of the same substance, which is also employed in pyrotechny and as an ingredient of percussion-cap mixtures. The oxides of antimony have many uses, not only as white pigments and opacifiers for the vitreous enamels of iron and steel articles and in the glass and ceramic industries, but also in the composition of special flame-retarding paints and of sprays for the fire- and mildew-proofing of various textiles. Other compounds form the basis for a number of yellow pigments. The trichloride is used for the 'browning' and 'bronzing' of gun barrels. Tartar emetic, potassium antimony tartrate, and other salts are employed as mordants in dyeing. Finally, the medicinal preparations of antimony should be mentioned, especially those used in the fight against *kala azar* and bilharziosis.

The Star Metal Refinery at Vikhroli, Bombay, completed during the second world war, is the only antimony-producing concern in India, deriving its ores from Chitral until the mines passed to Pakistan on the partition of the country in 1947. In that year 238 tons of the metal were made, rising to 330 tons in 1948 and falling to 100 tons in 1949. Indian imports of antimony ore totalled 571 tons in 1948 and 250 tons in 1949, derived from Burma, Siam, the United States of America and China (in 1948). For the six months ending June 1950, India imported 417 tons of antimony ore. The consumption of metallic antimony before partition is estimated to have been approximately 300 tons per annum, and it is expected to be doubled in the near future. During the five years 1939-43, inclusive, the average annual production of antimony ore from the Chitral mines was 442 tons; for the four years ending 1947 it was 1,167 tons, of a spot value of Rs 1,81,045, and since that time no further output has been reported.

The average annual world production of antimony ore, in terms of metal, for the five years ending 1938, was approximately 34,000 tons, about three-quarters of which came from China, Bolivia and Mexico. Until the invasion by the Japanese in 1942, China was the leading antimony-producing country, responsible for about 70 per cent of the world's supply, and in earlier years still for a good deal more than this. The chief ore deposits are in the provinces of Hunan, Kwangtung and Kwangsi. In the former a series of sediments, ranging from Silurian to Carboniferous in age, have been strongly folded and fractured, resulting in the shattering of

certain quartzite bands, the joints and cracks of which have been recemented by antimonite, which also replaces the rock to some extent. In other localities the stibnite is found in quartz veins of a more normal type. The decrease in Chinese production has led to the large-scale development of antimony ore deposits elsewhere, particularly in South America, so that of the world's production of 37,327 tons of antimony ore, representing say 26,000 tons of the metal, approximately 32 per cent came from Bolivia, 20 per cent from Mexico, 15 per cent from the United States and over 4 per cent from Peru; outside the Americas, South Africa is the largest producer with 11 per cent of the total in 1947, the stibnite here occurring in the auriferous reefs of the Murchison Range in the Transvaal. Antimony ores are widely distributed and eighteen other countries appear in the list of producers for 1948.

Stibnite is one of the most fusible of minerals and can be melted very easily, a property taken advantage of in the preliminary treatment of this ore, in which heat is applied and the molten sulphide run off into receivers as it drains away from the gangue and waste rock. It contains about 70 per cent of the metal and is referred to in the trade as Crude Antimony. The unrefined metal is termed *Regulus*, while *Star Antimony* is the name applied to the comparatively pure refined metal, doubtless from the characteristic markings on the surface of the ingots. It generally contains over 99 per cent of the metal, often, in the case of special brands, rising to 99·6-99·8 per cent antimony.

ARSENIC

Arsenic is a steely-grey, brittle metal with a bright lustre and scaly structure, a very widely distributed element and a constituent of a great number of mineral species, such as the sulpharsenides of copper, lead and silver and the various arsenates. Its chief primary mineral is arsenopyrite or mispickel, the sulpharsenide of iron, $\text{FeS}_2 \cdot \text{FeAs}_2$, which contains 46 per cent of arsenic; closely related to it are the arsenides of iron, löllingite, FeAs_2 , and leucopyrite Fe_3As_4 . They are all members of the marcasite group of minerals, marcasite being the orthorhombic form of iron pyrites, FeS_2 , and it is likely that mixed crystals exist which may contain any of them. The simple sulphides, realgar, AsS , with 70 per cent of arsenic and orpiment, As_2S_3 , with 61 per cent of arsenic, occur in Chitral and elsewhere. Practically all the arsenical compounds of commerce, with the exception of these natural coloured sulphides, are recovered as by-products in the roasting of the arsenical ores of other metals, such as copper, silver, gold and tin. Soots and flue dusts from such operations contain the crude oxide, which after purification is marketed as White Arsenic, arsenious oxide, As_2O_3 .

The orpiment mines of Chitral are of great age, and small quantities of the mineral are still obtained from them from time to

time, though for a great many years no returns of production were available, until 1945 and 1946, when a total of 11 tons was returned. According to G. H. Tipper, there are six principal areas in which they are situated—Mirasht Gol, Aligot, Londku, Wiznich, Mogomo Zom and Stach and all lie between 10,000 and 16,000 feet above sea level. The bright yellow trisulphide, orpiment, is usually associated with the brilliant aurora-red monosulphide, realgar, and with fluorspar, the minerals occurring close to a band of basic rock, intrusive into calcareous shale accompanied by marble. V. P. Sondhi visited the region in 1943 and found the occurrences extremely variable, ranging from mere stringers to local expansions up to 10 feet across. Small quantities of the sulphides were then being won at Aligot. For nine months of the year the workings are buried under deep snow, so that any large-scale developments in the foreseeable future are unlikely. Arsenical pyrites is also well known in Chitral, but as a source of arsenic or its oxide it could not compete with cheap imported products.

Both orpiment and realgar occur in scattered fragments on the moraines of the Shankalpa glacier in the Kumaun Himalayas, where they are collected and sold locally, doubtless furnishing part of the supplies of the cities in northern India, for the minerals can be purchased in specimen quantities in almost any bazaar.

Orpiment has been imported into Burma from the Chinese province of Yunnan for a great many years. Coggin Brown was the first foreigner to locate, visit and describe the mines, which lie at an elevation of 8,000 feet, in mountainous country, two days' journey to the south-west of Tali. The deposit is confined to a band of quartzite about four feet thick, of Permo-Triassic age, which has been thoroughly shattered in all directions. Orpiment and realgar have been deposited in the bedding, joint and fracture planes, and to some extent have replaced the minerals of the rock itself, forming irregular strings which swell into lumps and bands of solid sulphides. The quantity of orpiment coming into Burma from Yunnan used to fluctuate between 200 and 500 tons per annum, but the discontinuation of the compilation of the trans-frontier trade returns in 1924 makes it impossible to comment on what may have happened since that time.

The occurrence of arsenical pyrites on Samphar Hill, in the Kalimpong subdivision, Darjeeling district, West Bengal, originally described by F. R. Mallet in 1882, was re-examined during the second world war and found to consist of two seams, seven and six inches thick respectively, separated by a band of quartz schists, but their lenticular character did not favour further exploration. Samples of the seams contained from 9.7 to 27.17 per cent of arsenic. The occurrences of the iron arsenides, löllingite and leucopyrite, in the mica-bearing pegmatites of the Hazaribagh district, Bihar, possess no economic importance.

The most important metallurgical use of arsenic is in the preparation of arsenical copper, for with 0.1 to 0.5 per cent of arsenic the metal becomes harder and stronger and has better heat- and corrosion-resistance than the purer form. Arsenical copper is accordingly used for locomotive firebox plates and stays, for calico-printing rollers, for motor-car radiators and other articles that are assembled by soldering. Deoxidized arsenical copper is mainly used for welded vessels. The usual method of making arsenical copper is by the addition of arsenious oxide to the molten metal, followed by poling. Amounts up to 1 per cent of arsenic are added to lead which is to be used in the manufacture of shot. Arsenious oxide, or white arsenic, is an extremely poisonous compound and upwards of 70 per cent of the total world production is said to be used in the preparation of insecticides, such as the lead and calcium arsenates, for the protection of crops of various kinds from the attacks of injurious pests, while a further 20 per cent enters into the composition of weed killers. Fungicides, bactericides, sheep and cattle dips, preservatives for timber, skins, hides and leather, as well as arsenical soaps, are other outlets. White arsenic also has its uses in opalescent glass-making, in calico printing, in the fixation of aniline dyes and in many drugs for veterinary and general medical practice. Some of the lethal substances proposed for chemical warfare, such as lewisite (chlorovinyl dichlorarsine), owe their destructive power to the presence of arsenic. As its name indicates, orpiment (a corruption of the Latin *auri pigmentum* or 'golden paint') finds a direct use in the manufacture of Indian ornamental lac wares and of Burmese lacquer work. Powdered and mixed with gum it produces a so-called 'gold lacquer', while with indigo it forms green tints. In the designs of Afridi wax cloths advantage is taken of the colour of orpiment. The mineral is also widely used in the East as a depilatory.

There is a small but steady demand in India for arsenical compounds. - Thus during the five years 1913-14 to 1917-18, approximately 100 tons of arsenic and its oxide were imported annually, while over the decade ending 1943, this had risen to 185 tons, valued at Rs 4,31,043 per annum. The world's production of white arsenic in 1948 was 41,880 tons, out of which the United States were alone responsible for 17,290 tons. The severe competition from countries where white arsenic is produced as a cheap by-product would have to be met if it became possible to manufacture the oxide in India, in connexion with some future development of her base metal industry.

BISMUTH

Bismuth is closely related to arsenic and antimony and like these elements is found in the native state and in a number of similar natural compounds. Native bismuth is a very brittle, lustrous,

silvery-white metal with a pinkish tinge, a well-developed, straight, brilliant cleavage and a platy structure. On exposure its fresh surfaces tarnish rapidly. It can be cut with a knife and melts easily below a red heat, possessing the power of expansion on solidification. The ores which have been identified in India, or Burma, include the native metal itself, Bi; bismuthinite, bismuth sulphide, Bi_2S_3 , with 81.2 per cent of the metal; bismite or bismuth ochre, bismuth trioxide, Bi_2O_3 , with 89 per cent of the metal; bismutite, a basic carbonate of uncertain composition, but probably $\text{Bi}_2\text{O}_3 \cdot \text{CO}_2 \cdot \text{H}_2\text{O}$, and bismutosphärite, another basic carbonate with the formula $\text{Bi}_2(\text{CO}_3)_2 \cdot 2\text{Bi}_2\text{O}_3$.

Small quantities of bismuth have been reported from some of the copper ores of Singhbhum, with the nickel-cobalt ores of Bhorle in Nepal and with manganese ore at Siri on the borders of Kulu, E. Punjab. Bismuthinite and bismutosphärite have been found associated with galena, cerussite (the carbonate of lead) and barytes at Malthol, near Purulia, Manbhum.

A few hundredweights of bismuth ores have been exported from the Tavoy district of Burma from time to time: here both native bismuth and its sulphide occur in small amounts in some of the wolfram and cassiterite veins, as, for example, in those of Kanbauk, Kalonta, Zimba and Putletto. They have also been found in the adjoining districts of Mergui and Amherst. The bismuth minerals originated from the granites of Tenasserim, as those of tin and tungsten have also done, but they belong to a later phase of the ore-forming processes, as the metal is often found in thin filaments deposited on, or cutting through, the wolfram. The quantity of the bismuth minerals found in the veins is far too insignificant to permit of their profitable extraction on this account alone, and the small parcels of ore which have left Burma have been recovered as by-products in the sluicing of eluvial deposits for wolfram and tinstone, the heavy bismuth compounds accumulating in the sluice boxes with these concentrates. Under these conditions the native metal is always very oxidized and its coatings of bismuth ochres cause it to resemble small rounded pieces of dirty, yellowish-grey stone, which are often carefully picked out by tributors ignorant of their value and thrown away, although on breaking the larger pieces there is often a bright, metallic kernel within. It is well known that some of the tin-tungsten ores, not only of Burma, but also of Thailand and China, contain appreciable amounts of oxidized bismuth compounds, mainly in the form of the carbonates, and that they remain with the cassiterite when the wolfram is removed from the mixed concentrates by magnetic separation. From such tin ores the bismuth is recoverable by suitable chemical means, but no information is obtainable as to the quantities of Burmese ores so treated or of the amounts of bismuth so obtained. As far as existing methods on the mining fields themselves are concerned, the output from known sources is likely to remain extremely

small. It remains to add that large nodules of native bismuth are occasionally found in the gem-bearing detritus of the Ruby Mines region in Upper Burma, and that their source is completely unknown.

In normal times it is said that upwards of three-quarters of the world's production of bismuth is employed in the manufacture of medicinal and cosmetic preparations, but the metal is also used on a large scale for alloying with lead, tin, cadmium and other metals such as antimony. Such alloys are characterized by their low melting points and non-shrinking properties; for example the familiar Wood's metal with bismuth 50 per cent, lead 25 per cent, tin 12.5 per cent and cadmium 12.5 per cent, melts at about 70° C.; another, known as Rose's metal, with bismuth 50 per cent, lead 25 per cent and tin 25 per cent, melts at 94° C. Their industrial applications include fuses for automatic water-sprinklers which operate in the case of accidental fires, safety plugs for boilers, safety fuses for electrical apparatus, moulding and pattern metals, mountings for dies, punches and so forth, special solders, and fillers for bending thin-walled tubing of other metals from which they can afterwards be steamed out. Large quantities of bismuth and its alloys are said to be used in the production of atomic bombs and radar equipment. Bismuth amalgams are used in dentistry; the carbonate and nitrate are the chief pharmaceutical compounds.

It is estimated that before the second world war the total consumption of bismuth was in the neighbourhood of 1,300 or 1,400 tons annually and it has probably increased greatly since then, but complete and accurate data are not available. Twenty years ago Bolivia was the main source of supply, the bismuth ores forming part of a tin-tungsten-base metal sulphide assemblage recalling that of Lower Burma. Peru is now the leading producer, the bismuth being obtained as a by-product in the smelting and refining of lead and lead-silver ores. The Mexican output comes largely from the flue dusts of smelters treating copper and copper-silver ores. The Canadian production too is a by-product recovery from lead and copper ores. Bismuth ores seem to have been reported from most of the important mining fields of the world, though rarely in substantial quantities; at the same time the list of producing countries is a long one including as it does Spain, Yugoslavia, Sweden, Germany, France, the Soviet Union, China, Australia, the Belgian Congo and South Africa.

The price of metallic bismuth, which had fallen from 12s. 6d. in 1920 to 3s. 6d. per lb. in September 1935, had risen again to 17s. per lb. in December 1950.

CADMIUM

Cadmium has been described as 'the rarest of the common metals'. It is soft and silvery-white in appearance, malleable,

ductile and easily fusible. A close relative of zinc, it normally occurs in zinc ores to the extent of from 0.1 to 0.4 per cent, probably in the form of the sulphide, greenockite, CdS . It is also found in very small amounts in other metallic ores, and is recovered on a commercial scale not only from the products volatilized during the roasting of zinc ores and from the leach liquors of the electrolytic process of zinc manufacture, but also from the dust- and fume-collecting equipments of copper and lead smelters.

The zinc blende of the Bawdwin orebody in Burma is known to contain small quantities of cadmium. Zinc concentrates from the Zawar mines of Rajasthan average 0.2 per cent of the metal. A specimen of zinc blende from the Great Limestone, near Darabi, Riasi *tahsil*, Kashmir, contained 0.17 per cent cadmium.

Just as the major use of zinc in normal times is in thin coatings to protect iron and steel sheets from atmospheric corrosion and to be seen all over the world in the form of 'galvanized' corrugated sheets, wire netting and fencing, pipes, tubes, bolts, nuts, screws and so on, so the major use of the rarer and much more expensive sister metal cadmium in the past has been to electro-plate more important iron and steel articles with a resistant, rust-proof coating, to be found for example in aircraft parts and the fittings of motor cars. Cadmium is also an essential component of the high duty alloys used for the bearings of internal combustion engines, lowering the coefficient of friction, adding strength and increasing fatigue-resistance, particularly when coated with small amounts of indium, another rare metal not as yet identified in India. Such alloys may contain from 95 to 98 per cent of cadmium with small additions of nickel, or of silver and copper. Cadmium lowers the melting point of solders, and with bismuth, lead and tin is a component of the fusible alloys more fully described under **BISMUTH**. Small amounts of cadmium are added to pure copper to be used in the form of wires for long-span overhead cables, for by this means the strength of the metal is greatly increased with a minimum sacrifice of electrical conductivity. Similar cold-worked copper with about 0.9 per cent of cadmium is extensively employed for trolley wires and other purposes. As cadmium has a high absorption capacity for neutrons it has been made into rods for the control of some types of atomic piles, the reactions within which can be decreased or intensified by winding the rods in or out as required, but it is not the only element adopted for this purpose.

Salts of cadmium, apart from those used in electro-plating, have a number of industrial uses; the sulphide forms the brilliant pigment known as Cadmium Yellow, the sulphoselenide is Cadmium Red. These, and a whole range of related colours, are used in paint-making as well as for ceramics and inks and the processing of rubber and leather goods. Other compounds are used in luminescent pigments and in photography. The colouring agents most frequently used by Indian bangle-makers are cadmium sulphide and

selenium, besides the oxides of cobalt and copper. Cadmium sulphate is employed in standard electric cells for the accurate determination of electric pressures.

The average world production of cadmium for the five years ending 1938 was a little more than 4,000 tons, which came, of course, from the countries mining and smelting zinc ores or from others which make zinc from imported ores. Thus about half of the 4,000 tons came from the United States of America and the remainder from Mexico, Canada, Germany, Australia, Poland and Belgium. In 1947 the United States alone produced over 3,600 tons, Mexico over 760 tons and Canada about 330 tons. For a number of years the Australian production has averaged about 230 tons per annum.

Cadmium is a costly metal; its production figures are usually stated in pounds avoirdupois or kilograms and in the American and British markets it is sold by the pound. The London price of 5s. 4d. per pound in 1945 had risen to 17s. 3d. per pound by the end of 1950, the equivalent of £1,932 per ton.

GALLIUM

Gallium, a member of the family of elements which also includes aluminium, indium and thallium, is one of the scarcest metals although traces of it are to be found in many common ores. Its existence was predicted by the Russian chemist Mendeléeff in 1871, under the name *eka-aluminium*, and it was discovered by the French chemist L. de Boisbaudran in 1875, in a zinc blende from the Pyrenees. Today, it is recovered from the flue dusts of zinc smelters, from the residues of zinc refineries, and, like germanium, from the flue dusts of gases from producers burning certain types of coal. It occurs in some bauxites, the ores of aluminium, and has, indeed, been identified in specimens from Salgipat north of Lohardaga, Bihar, by B. Mukherjee and R. Dutta. Residues from the various industrial processes using bauxite in India, including those of the aluminium works, merit examination as possible sources of supply. Gallium has also been found in quartz from the Kangundi gold mine in Chittoor, Andhra, and in both manganese ore and mica from Nagpur, Madhya Pradesh. The metal itself, which is most conveniently obtained by the electrolysis of aqueous solutions of sodium gallate, has some unusual properties, for it is a silvery-white crystalline solid which melts at 30° C., so that it liquifies when held in the hand. It behaves rather like mercury in forming amalgams, and it alloys easily with other metals, but it does not boil below 1200° C., compared with 357° C. for mercury. Apart from its use in the construction of high-temperature thermometers it has no outstanding industrial applications at present, but its unique properties will no doubt be turned to commercial account when larger supplies become available.

GERMANIUM

Germanium is a greyish-white crystalline and brittle metal allied to tin, and originally isolated by the German chemist Winkler from the sulphogermanate of silver, argyrodite, thirteen years after Mendeléeff had predicted its properties with remarkable accuracy. It also occurs in a few other rare natural compounds of similar character, but on a commercial scale is obtained mainly from the residues of zinc refining works in America and from the flue dusts of coal in Britain. Many English coals are reported to contain germanium to the extent of 10 to 20 parts per million, which becomes concentrated chiefly in the dusts of flues of installations burning producer gas made from them. Such dusts, according to A. R. Powell of Johnson Matthey & Co., may contain up to 1 per cent of germanium and of gallium, though their general content is from 0.25 to 0.75 per cent of each of the two elements. The germanium is separated from them as its tetrachloride, a liquid which boils at 85°C ., which is then hydrolized to obtain the dioxide. This, on reduction by hydrogen, yields the metal. According to B. Mukherjee and R. Dutta, ashes from coals of the Garo Hills of Assam contain from 0.095 to 0.122 per cent of germanium, while those from coals of the Singareni and Tandur fields of Hyderabad contain from 0.055 to 0.065 per cent and 0.017 per cent respectively of the same element. The whole question of the occurrence of germanium in Indian coals needs fuller investigation.¹

Germanium is a semi-conductor and its resistance to the passage of an electric current decreases with a rise in its temperature, a reversal of the behaviour of a normal metallic conductor, and a property which can be utilized in the construction of thermistors. These are small and extremely sensitive devices for measuring temperatures. The metal is also used in instruments for the determination of the strength of magnetic fields, but it is in the field of electronic developments that it is becoming of increasing importance. Herein, it is used as a crystal rectifier in the detection of very high-frequency electric waves, such as those used in radar, and in various types of transistors which amplify currents and perform other functions usually done by thermionic valves. Radio broadcasting receivers have been demonstrated which employ a germanium crystal rectifier, as well as germanium crystal triode valves as amplifiers, in both radio-frequency and audio-frequency stages. Germanium diode and triode assemblies have advantages over the thermionic valve in that they require no heating, are of small size, rugged construction and operate instantly when switched on. They are of great service in many types of electronic circuits including computing machines, small radio receivers, deaf-aid amplifiers and in general industrial work of this kind. In August

¹ Prof. S. N. Bose and R. K. Datta have recently recorded 0.24 per cent germanium in magnetite associated with sphalerite from Nepal.

1953 germanium metal was quoted on the United States market at 65 cents per gram or \$295 per pound and germanium dioxide at \$142 per pound; the approximate sterling equivalents of these three dollar prices at prevailing rates of exchange being £0.4-8, £105.7-0 and £50.14-0 respectively.

MERCURY

Mercury, or quicksilver, one of the heaviest of the elements and the only pure metal that is liquid at ordinary climatic temperatures, occurs naturally in small quantities, but is for the most part obtained from its sulphide, cinnabar, HgS , a mineral which is mined chiefly in Italy, Spain and the Americas. Various occurrences, both of mercury and of cinnabar, have been reported from India and Burma, but the evidence for their existence is not trustworthy and those that have been examined have proved spurious. P. Viswanathan has recorded 'crimson grains of cinnabar' in the black beach sand concentrates from Needakara near Quilon, Travancore-Cochin state. Recently, a reported occurrence of mercury near Sakoli in the Bhandara district of Madhya Pradesh has been found on investigation to be a case of salting. In Pakistan, however, cinnabar has been definitely identified in the concentrates of the gold washings from the Chitral river, 'pointing', to use the words of Sir Lewis Fermor, 'to the existence of a deposit of this mineral somewhere in the State'. In most parts of the world, the ores of mercury are geologically young and their distribution is related to the folding and fracturing associated with the Alpine-Himalayan mountain systems. It is, therefore, not beyond the bounds of probability that they may occur in the as yet vast unprospected region which stretches from Assam to Kashmir and beyond, especially as they are known to exist in north-west Yunnan to the east and in Afghanistan to the west.

Mercury has manifold uses ranging from scientific instruments such as thermometers and barometers, electrical contacts, arc rectifiers, automatic switches and control devices to mercury-vapour lamps and the mercury-vapour boilers of large power installations. It is employed in the electrolytic preparation of chlorine, caustic soda, acetic acid and acetone. Many metals, including gold, silver and tin, dissolve in mercury to form alloys known as amalgams, and advantage is taken of this in the recovery of gold from its ores and in the preparations used in dentistry. Many salts of mercury are of great utility: the red mercuric oxide in dry battery cells, and in anti-fouling paints for ships; the fulminate as a powerful detonating explosive; the bright scarlet sulphide as a pigment in paints and printing inks; both mercurous and mercuric chloride play an important part in medicine, the former being the well-known drug, calomel, and the latter corrosive sublimate, an antiseptic, fungicide and insecticide of note. Other compounds of mercury are employed in the manufacture of plastics, dyestuffs and other chemicals.

The average annual world production of mercury during the period 1934-8 was 3,950 tons, upwards of 70 per cent of which was represented by the combined output of Spain and Italy, with smaller amounts from the United States of America, the Soviet Union, Mexico, China and other countries. The 1947 production was estimated at about 5,300 tons, to which Spain and Italy contributed approximately 60 per cent. In 1950, the output from the Almaden deposits of Spain rose to between 118,000 and 120,000 flasks, the wrought iron receptacles in which the metal is stored and transported. The standard flask contains about 76 lb. of mercury and forms the market unit of quantity. In December 1950 the London price was a nominal one of £37-10-0 per flask.

RUBIDIUM AND CAESIUM

The elements lithium, sodium, potassium, rubidium and caesium together constitute the alkali group of metals. They are all silvery-white in colour, exceptionally light in weight (lithium being only about half the weight of water), soft enough to be cut with a knife, tarnish rapidly in air and decompose in water at ordinary temperatures. Lithium, rubidium and caesium are the rarer members of the group, in the order named, and they are generally found together in their natural compounds, though lithium is far more abundant than either of the other two. The lithium-bearing minerals so far identified in India, lepidolite, spodumene and amblygonite, have been described under LITHIUM, but in only one of the occurrences, that of the lepidolite, or lithium mica, from Pipra in Bihar, has the presence of rubidium, to the extent of 0.07 per cent of its oxide, Rb_2O , and of traces of caesium, been confirmed. In the lepidolite from Mundaval in Bastar only rubidium has been detected spectrographically. This is probably because the others have not been fully investigated chemically. Traces of caesium are also suspected in the composition of the green, roscoelite micas, described by S. K. Chatterjee, from Mahalgaon, Bhandara district, Madhya Pradesh. When investigations into the prevalence of these rare alkali metals in India are undertaken, the microcline feldspars from the mica-bearing pegmatites of Bihar, Andhra and Rajasthan should be particularly examined, as well as the beryls from the last named State. Such feldspars from pegmatites in south-west Maine, U.S.A., have been found to carry up to 3 per cent of rubidium oxide and over 0.5 per cent of caesia. A publication by the Principal Mineralogist of the United States Bureau of Mines and others, gives the information that rubidium occurred in at least fractional percentages in every specimen of forty-four microclines tested from the pegmatites of Maine, Massachusetts, Connecticut and New Hampshire, and that in twenty-two of the forty-four, a content of 1 to 3 per cent of rubidia was indicated. Lepidolite from the same States nearly always contains some caesium

and rubidium. An amazonite (green microcline) from the Ilmen Mountains of the Soviet Union contains over 3 per cent of rubidia, while a microcline from Varutrask, Sweden, is reported to carry 3.3 per cent rubidia, 0.6 per cent caesia and 0.34 per cent lithia. In such feldspars the rarer alkali metals replace part of the normal potassium in the formula $K_2O \cdot Al_2O_3 \cdot 6SiO_2$. Although rubidium is more plentiful than caesium it is not known to form any definite mineral species of its own. Caesium has only one natural compound, its hydrated silicate with aluminium, pollucite, an exceedingly rare mineral which has been found in a pegmatite on the Isle of Elba, in another in Sweden and in a few in Maine and Dakota, U.S.A., as well as at Karibib in South-West Africa.

The metals themselves can be prepared by the electrolysis of fused chloride melts, or by the vacuum distillation of their oxides with aluminium, but they are usually marketed as chlorides or nitrates. Rubidium compounds are stated to have importance as microchemical reagents. Caesium salts are chiefly employed in the manufacture of photo-electric cells, electron multipliers, the screens of television cameras and in the so-called 'black light' and other signalling devices.

SELENIUM

Selenium is a non-metallic element, closely allied to sulphur, which forms the natural selenides such as clausthalite, the selenide of lead, $PbSe$, and berzelianite, the selenide of copper, Cu_2Se , the analogues of the sulphides, galena, the sulphide of lead, PbS and chalcocite, Cu_2S , a sulphide of copper, respectively. Selenium occurs in native sulphur and in most ores of a pyritic character, though often in very small quantities. There is reason to suspect its presence in the copper ores of Singhbhum and in the lead-zinc-copper ores of Bawdwin, in the Shan States, but in neither case are analyses of the waste products forthcoming, in which it may have accumulated during their treatment. The element is never abundant enough to be mined alone for its own sake and commercial supplies are obtained as by-products during the electrolytic refining of blister copper, as both selenium and tellurium remain in the sludges from which they are recovered. Smaller quantities are also obtained from deposits which accumulate in the lead chambers during the manufacture of sulphuric acid.

The principal application of selenium is in the glass industry, as a neutralizing agent of the greenish colour imparted to glass by small amounts of iron, and for this purpose it is said to be displacing manganese dioxide. Larger percentages give pink, red and ruby tints to glasses which are manufactured for such purposes as railway signal lights, the rear lights of motor vehicles and the like. Mixtures of selenium and varying amounts of cadmium sulphide afford a whole series of glass and ceramic pigments, ranging from yellow to

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red, and are, in fact, the colouring agents most frequently used by Indian bangle-makers.

Selenium, like sulphur, exists in several allotropic forms, and one of them, a silvery-grey crystalline solid, the so-called 'metallic selenium', varies in electrical resistance with the intensity of the light to which it happens to be exposed, and for this reason is used in the construction of photo-electric cells. These play an essential part in the 'talking pictures' of the cinema, in the transmission of photographs and sketches by 'wire', as well as in photographic exposure meters, scanners, counters, remote control apparatus, optophones, smoke and turbidity measuring instruments, automatic devices for lighting street lamps and buoys at sea, electric signs, as well as those for the opening and closing of doors, for burglar alarms and mechanical safety devices. Selenium is also employed in rectifiers for the conversion of alternating into direct electric currents. It is added to some forms of stainless steel and to certain copper alloys to improve their machining properties. The rubber industry uses it as a toughening agent for such products as cable coverings for mines and ships, for machine beltings and shock-resisting blocks and pads. In such examples it is said to confer on rubber a number of desirable attributes unobtainable by the use of sulphur alone.

The world's annual production of selenium is probably in the neighbourhood of 550 tons, and it is derived almost entirely from the major copper refining countries whose output is usually expressed in pounds avoirdupois. Thus in 1947, the United States produced 612,600 lb., and Canada 501,090 lb., falling to 327,500 lb. in 1948, while the slimes of the Northern Rhodesian copper refineries yielded 27,056 lb. in 1950. About the middle of 1950, selenium was obtainable at a cost of 14s. per lb., but by the end of the same year this had risen to £1-5-0 per pound.

TELLURIUM

Tellurium is a brittle silvery-white element, resembling antimony in outward appearance, which lies on the borderline between the metals and non-metals: closely related to selenium and sulphur in many of its chemical properties, it does, at times, act like a true metal. It occurs in the native state and is widely distributed in small amounts, often in association with the ores of gold, silver, lead and copper. Altaite, the telluride of lead, $PbTe$, the analogue of the selenide clausthalite, $PbSe$, and of the sulphide, galena, PbS , occurs with gold at Kyaukpazat, Katha district, Upper Burma. Tellurides are also known to occur with the gold of the Oriental Lode of the Kolar goldfield; with copper sulphides in the gold-bearing quartz veins of Lawa, Manbhum, Bihar, and with the copper ores of Sikkim, but to which particular mineral species these Indian tellurides belong still awaits determination, except in the

case of Sikkim, where tetradyomite, the telluride of bismuth, Bi_2Te_3 , has been identified.

At the present time copper ores are the chief source of tellurium, and it is recovered as an oxide from the slimes of the electrolytic copper refineries, after their selenium contents have been removed. The oxide is reduced in crucible furnaces by means of flour and borax and the dark grey tellurium cast into 80-lb. bars.

Tellurium, like selenium, is used in the vulcanizing of rubber, to increase its toughness and abrasive resistance, as well as to improve the quality of certain ferrous and non-ferrous alloys. Minute quantities added to cast iron are said to increase its resistance to abrasion and to make it more suitable for such purposes as car and gear wheels. Small percentages of tellurium added to lead augment its strength and toughness, as well as its resistance to heat, vibration and corrosion. Pipes made of such alloys can, after suitable treatment, be made one third thinner than ordinary lead piping and yet possess greater strength. Tellurium-lead, however, finds its chief outlets in chemical engineering, as, for example, in pickling-tanks to contain hot sulphuric acid. One half of one per cent tellurium is reported to double the life of lead apparatus in sulphuric acid plants.

Fifteen years ago the total annual world production of tellurium is reported to have been less than one ton, but by the 1936-9 period this had risen to about 33 tons annually. The United States and Canada are the chief producers, the former giving 52,290 lb. in 1947 and the latter 32,100 lb. in 1948. At the end of 1950 the London price of tellurium was 14s. 4d. per pound.



PART III

MATERIALS USED IN BUILDING
CONSTRUCTION, CIVIL ENGINEERING, ETC.

CHAPTER IX

BUILDING MATERIALS

BUILDING STONES

To attempt even to summarize our knowledge of Indian building stones in a brief compass is an impossible task and all that can be done here is to invite the reader's attention to some of the better-known types. The stones used in any particular area depend almost entirely on the type of rock lying nearest to hand. In the cities of the plains, most buildings are usually built of locally made bricks and coated with stucco, but in many others the surrounding tracts furnish supplies of stone when these are required for more important purposes.

There are few places in southern India where crystalline rocks such as granites, gneisses and charnockites are not available, and they have been used from the time of the builders of the prehistoric megaliths onwards. As a modern example, granite from Lingampalli, in Hyderabad, was used exclusively in the construction of the harbour works at Bombay, while similar rocks from Munirabad and Raichur, in the same State, are of exceptional quality for similar heavy civil engineering purposes, according to K. Mirza. Many of the older Dravidian temples in the south, architectural works of great beauty and noble proportions, are built of such crystalline rocks, which have also furnished the stone for their carvings, both of statues and scrolls, 'the elaborate patterns on which are as sharp as when they left the sculptor's hands'. In recent times granite setts have been exported from southern India to pave the roads of foreign cities, while today the same rock is cut and polished at a factory in Bangalore and exported to the United Kingdom for monumental and memorial purposes.

Much of western and central India, Bombay, the Deccan and parts of Madhya Pradesh are occupied by eruptive lavas, generally termed the Deccan Trap, which prevail over an area of about 200,000 square miles. In many localities they supply excellent building stones, provided the proper varieties are chosen, while the Lameta, or infra-Trappean beds, of Madhya Pradesh yield a good ragstone which has been successfully employed in bridge-building. On the other side of the peninsula, the traps of the Rajmahal Hills have been quarried for centuries. They supply Calcutta with road metal and have been used in river training works on the Ganga (Ganges). The resistance of the Deccan Trap and similar eruptive

rocks to the ravages of time is proved by the fact that the world-famous caves and rock temples of Ajanta and Ellora, dating from about the eighth century A.D., are chiselled out of solid trap.

Several of the Indian geological formations furnish sandstone suitable for building and engineering works generally, but amongst them pride of place must be given to the Vindhyan System, which from the time of Asoka (269-32 B.C.) has, throughout the centuries, supplied incomparable materials in which the craft of the stone-cutter and the skill of the architect have left enduring expression. The Kaimur sandstones of this system are quarried at Dehri-on-Son, in the Shahabad district of Bihar. Further west, at Mirzapur, Chunar and elsewhere in Uttar Pradesh, they have been quarried for ages and the stone is well known throughout the Ganga valley for its superb qualities. It is fine-grained and compact, generally pale red to grey in colour and extremely durable. It is still widely used in the construction of temples, memorials, houses and for sculpturing as well as for girder bed-stones in bridges, flooring and coping as well as kerbing and channelling. Massive, individual beds often spread long distances without joints or fissures so that very large blocks can be quarried. From the Chunar region Asoka is believed to have obtained his pillars, great monoliths weighing up to 50 tons which, polished and inscribed with the Emperor's edicts, were erected at localities often hundreds of miles away, bearing eloquent testimony to the ability of those concerned in their production, finishing, transport and erection in the Mauryan age. Of the magnificent capital of the Sarnath pillar which is of the bell-shaped type with four lions above, supporting in their midst a stone wheel or *dharmachakra*, the symbol of the law, Sir John Marshall, a former Director of Archaeology in India, has written: 'Both bell and lions are in an excellent state of preservation and masterpieces in point of both style and technique—the finest carvings, indeed, that India has yet produced, and unsurpassed, I venture to think, by anything of their kind in the ancient world.' The opinion of another authority, the late Vincent Smith, is also worth quoting: 'The skill of the stone-cutter', he wrote, 'may be said to have attained perfection. Gigantic shafts of hard sandstone, thirty or forty feet in length, were dressed and proportioned with the utmost nicety, receiving a polish which no modern mason knows how to impart to his material. Enormous surfaces of the hardest gneiss were burnished like mirrors, bricks of huge dimensions were successfully fired, and the joints of masonry were fitted with extreme accuracy.' The richly sculptured Bharut railing, originally around a stupa in Nagod, Baghelkhand, and now one of the treasures of the Indian Museum in Calcutta, and the stupa built of red sandstone blocks, as a segment of a sphere with a diameter of 110 feet at the base of the dome, and a height when perfect of about $77\frac{1}{2}$ feet, at Sanchi in Bhopal, together with its massive stone railing of monolithic pillars, 11 feet high, and its four highly ornate gateways, each

34 feet in height, covered with relief sculptures illustrating the Buddhist scriptures, are further noble records of this early age of Indian work in Vindhyan sandstones. In Madhya Bharat the forts, temples and palaces of Gwalior are constructed of similar material.

'Perhaps the most important quarries in India', wrote V. Ball, 'are those in the Upper Bhanders (the uppermost series in the Vindhyan System), to the south of Bharatpur and Rupbas, in Rajputana and Fatehpur Sikri in the Agra district of the United Provinces, which have furnished building materials since before the commencement of the Christian era to the cities of the adjoining plains. Portions of the Taj at Agra, Akbar's palace at Fatehpur Sikri, the Jumma Masjid and, it may be added, many other magnificent mosques and tombs and generally the grandest and meanest buildings in Agra, Delhi and Muttra have drawn upon these quarries for their materials.' The historic Mogul buildings of Lahore too are built of the same Vindhyan sandstones transported from quarries near Bharatpur and Fatehpur Sikri. The *Ain-i-Akbari*, written by Abul Fazl in 1590, refers to the 'red stone which is cut out of the mountains of Futtapore' and used for building purposes, and it also mentions the prices at which the Emperor Akbar permitted both rough and dressed kinds to be sold. Further west in Rajasthan, the hills near Jodhpur are capped with sandstones of Upper Vindhyan age from which, according to T. D. La Touche, 'inexhaustible supplies of the most excellent building stone may be obtained. The finer beds afford material not only for the walls of houses, but also for beams to support the ceilings as well as flags for roofing and flooring. The stone is of a soft reddish tint, easily worked and thoroughly durable, and is susceptible of the most delicate carving. Splendid examples of its architectural capabilities may be seen in the old palace and fort at Jodhpur.' To come to more recent times, the best buildings in Karachi are built of the same excellent stone. Thus the Vindhyan System supplies an immense tract in both India and Pakistan, stretching from Bengal to the far west, with stone of an unsurpassed quality of which are built the finest edifices and cities of the Gangetic valley, the religious memorials of the Mauryan period, the proudest monuments of the Mogul dynasty and, in more modern times, some of the largest engineering works of the British administration.

Other examples of the use of sandstones include those of Gondwana age in restricted areas of Bengal, Bihar, Orissa, Madhya Pradesh and Vindhya Pradesh. Modern buildings on the coal-fields of Bengal and Bihar and the ancient, richly decorated temples of Orissa and Chanda are alike constructed from them. As a rule they are fairly soft, medium- to coarse-grained, often rather felspathic stones of grey or pale buff shades, and though neither so pleasing nor so durable as those of Vindhyan age, are very cheaply worked. Sandstones and sandstone-quartzites of the Iron Ore

Series in Singhbhum are quarried for local building purposes. They too are light grey or pale buff stones, often with a greenish tint, which weather very well and can be used in the most exposed positions. Sandstones of Jurassic age are plentiful and extensively utilized in Kutch. In the coastal regions of the extreme south, particularly in the Tirunelveli district, ancient Hindu temples and modern Christian churches are constructed of a gritty, calcareous sandstone of sub-Recent origin. Quartzites of the Alwar Group are quarried in Alwar itself and in Ajmer-Merwara, while a bedded quartzite of Dharwarian age has been used in the Bhandara district of Madhya Pradesh.

Perhaps the best-known building material of the calcareous group of rocks is the famous 'Porbandar Stone', so much used in Bombay and other cities. It is a fine-grained white or buff limestone consisting chiefly of foraminiferal tests cemented by calcite, with a few oolitic granules and mineral fragments. It is of aeolian origin and is quarried along the western base of the Barda Hills of Saurashtra. At Aditania, states B. C. Roy after a recent visit, there are no less than 318 quarries, worked by some 42 parties in this miliolite limestone. They are scattered over an area of about one square mile at an elevation of 296 feet above sea level. The limestone band varies from 5 to over 100 feet in thickness and is usually quarried to a depth of 30 to 40 feet, though exceptionally, as at Dhoba, it has been removed to a depth approaching 100 feet. A railway siding, 5 miles in length, ensures easy transport from the quarries which for many years have supplied material for the frontages, columns, balustrades, etc., of public buildings, palaces, temples and other important architectural works, not only in Saurashtra and Bombay, but as far afield as Karachi, Madras, Calcutta and Rangoon. Moreover, the waste chippings from the quarries are utilized by the Associated Cement Companies at Porbandar and by the Tata Chemical Works at Mithapur, their monthly needs amounting to about 5,000 and 6,000 tons respectively.

The flaggy limestones of the Bhima Series (probably of Lower Vindhyan age) are worked for building purposes and for flagstones in the Bijapur district of Bombay and in the adjoining Gulbarga district of Hyderabad; usually of grey tints, there are also black varieties which take a fine polish. Crystalline limestones of Archaean age are quarried for floorings and for decorative uses in the Warangal district of Hyderabad. Shaly Aravalli limestones are utilized in Bundi and Nimbahera limestone in Udaipur, Rajasthan. The town of Jaisalmer, in Rajasthan, is built of limestone of Jurassic age which is quarried on a large scale in the vicinity. In the Narmada valley the coralline limestones of the Cretaceous Bagh Beds supply a useful stone. Cretaceous limestones are also quarried for building purposes in some parts of the Tiruchirappalli (Trichinopoly) district of Madras. The Narji Limestone, from the lower part of the second stage of the Kurnool Series of south India,

is the principal building material of the Cuddapah district and is also widely employed in the Kurnool and Guntur districts of Andhra. The stone is very compact, extremely fine-grained and from bluish-grey to black in colour. It has been incorporated in parts of the buildings of the University of Madras and is marketed not only in the cut and roughly dressed state, but also in a highly polished condition in various geometrical shapes for ornamental flooring and table tops. It is interesting to note that the Kurnool formation of southern India, from which this stone is derived, is probably the equivalent in time of the Lower Vindhyan rocks further north. A dark bluish limestone of doubtful Lower Vindhyan age is won extensively at Sikosa, Drug district, Madhya Pradesh, and used for flooring in Nagpur. The Pem limestones of Cuddapah age in the Chanda district of the same State are worked at Kandara. Finally, the coral formations which fringe the Tirunelveli and Ramanathapuram coasts for some 80 or 90 miles, and extend into the small islands of the Gulf of Mannar, are drawn upon for buildings in Tuticorin and other places.

Turning now to Pakistan, Baluchistan, in the west, possesses vast resources of limestone, much of which is good building stone, but it has been but little used. Quetta, the capital and only city, is subject to violent earthquakes and buildings of more than one storey are for this reason few. For the predominant single-storied buildings brick has proved more convenient, while the humbler homes are made of mud or mud-and-gravel mixtures. The chief building stone of the North-West Frontier Province is limestone, or its altered derivative marble, a subject discussed in another section, but sandstone and quartzite serve the same purpose in some places. In the northern and western parts of the Hazara district, advantage is taken of the property of the local gneissose granite which splits readily into suitable slabs. Triassic limestone is quarried near Abbottabad and furnishes a good, durable stone of somewhat sombre colour. The harder courses of the Murree Sandstones, in the south of the district, are easily worked and give a stone which lasts fairly well. Finely foliated schists are used for roofing purposes in some localities, as are the more fissile varieties of the acid volcanic rocks of the Karaman Range in the Mardan district. In the Himalayan part of the Punjab, dolomites and quartzites, as well as some of the harder Tertiary sandstones of the outer hills, supply good building stones. The Purple Sandstone at the base of the Salt Range Cambrian, and the overlying Magnesian Sandstone, have both given large quantities of stone for buildings and canal works in the Jhelum district, while a band of pisolitic ironstone at the base of the Nummulitics has been quarried for ornamental uses. The remainder of the great alluvial plain of the Punjab has to rely upon brick for building construction. In Sind, although Vindhyan sandstones imported from Jodhpur were used, together with a miliolite of Manchar age, not unlike the

Porbandar stone, Tertiary limestones are the principal materials. Khirthar (Eocene) stones are quarried at Sukkur and Rohri for the Indus barrages as well as at Kotri, Hyderabad and elsewhere for general purposes. A whitish or brownish-yellow, rather porous stone from the Miocene Gaj Beds has been employed in Karachi, while a fine-grained, light yellowish-brown limestone is won at Jhirak and other localities; of Ranikot (Lower Eocene) age, it is used in many parts of Lower Sind for tombstones and memorials over graves, often elaborately carved and engraved with inscriptions in Persian characters. In Eastern Pakistan building stones are virtually non-existent, as also are suitable materials for road metal, railway ballast, concrete aggregate and so forth. The Tertiary sandstones of the Chittagong Hill Tracts are too soft and too easily eroded for these purposes, though harder bands may yet be found among them.

In Burma, excluding the capital Rangoon, there is little demand for building stone, as domestic architecture finds its almost universal expression in wood. This is fortunate, as the soft Tertiary rocks which cover most of central and Lower Burma, west of the Sittang river, are remarkably deficient in building products. Outside these regions, however, in the districts of Lower Tenasserim, in those of Upper Burma, north of Mandalay, and in the Shan States, there is an abundance of many varieties of suitable stones if they are ever required. As it is, such masonry work as exists in the towns throughout the Union, and in the pagodas which are to be found everywhere, has used brick as its raw material. The civil engineers of the Public Works Department found that harder bands of the Tertiary sandstones of the Myitkyina, Shwebo, Lower Chindwin and Pakokku districts served well enough for the revetments and abutments of their bridges. Laterite was also used for the construction of culverts and small buildings in those districts of Lower Burma in which it occurs, due care being exercised to see that a suitable variety of this inconstant rock was chosen. In the Shan States, harder bands of the Namyau sandstones, of Jurassic age, were successfully utilized for bridge piers.

Statistics of India's stone quarrying industry are incomplete and thoroughly unsatisfactory, for while the output of some of the larger concerns was accurately known in the days of the British administration, the returns from many of the Provinces and States, particularly as regards small and scattered workings, were often little better than guesses on the part of local officials who possessed little supervisory authority over them. Lumped together, such as they are, under the heading 'Building Materials and Road Metal', they show an annual value today of over Rs 3 crores, and, at best, this can only be a partial estimate. The separate items include granite and gneiss, laterite, lime, limestone (including dolomite), *kankar*, marble, sandstone, slate, trap and a 'miscellaneous' group of unknown composition which far exceeds the others in weight and value.

Using such data as are available, the average annual production of granite and gneiss over the decade before the separation of Pakistan, that is from 1937 to 1946, and including the figures for Burma up to 1936, was 1,072,025 tons, compared with 1,199,117 tons per annum over the previous decade, 1927-36. To the former total Bihar contributed 41·7 per cent, Madras 34·1, Uttar Pradesh 9·2, the Punjab 8·2 and Bengal 4·0 per cent, the remainder coming from various other regions. For the years 1947-9, inclusive, the official returns show an average yearly production of only 147,938 tons, which can but be regarded as a very incomplete return.

Over the decade ending 1946, the annual outturn of sandstone amounted to 402,120 tons, compared with a yearly average of 414,750 tons during the decade which preceded it. For the first-named period (1937-46), no less than 88·4 per cent of this stone came from Rajasthan, Bihar following a poor second with 6 per cent, and a number of other States adding to the remainder.

Basic igneous rocks, generally referred to as 'trap', are quarried mainly in Bombay, a State which was responsible for 73·5 of the annual average of 464,650 tons for the period 1934-8, while a further 25 per cent came from Bihar. Later returns are too incomplete for useful comparison, but, in both the cases cited, most of the output was probably used as road metal rather than as building stone.

Some varieties of laterite have been mentioned as ores of iron, manganese and aluminium; others are used as dressings for unmetalled roads, while the compact, ferruginous kinds are sometimes utilized as building material as they are easily cut and dressed and slowly harden on exposure to the air. No proper records are kept in the various States of the quantities used for each of these separate purposes, and in the aggregate they are certainly very much larger than the selected figures submitted to the collecting authorities suggest; moreover, even these show extreme variations from year to year. For these reasons they are not summarized here. Laterite quarrying is of commercial importance in Travancore-Cochin, Bombay, the Deccan, Madhya Pradesh, Orissa (Puri district), Mysore, Andhra and Madras, especially in the East Godavari district of Andhra and the Malabar, South Kanara and Chingleput districts of Madras, as well as in Lower Burma.

The average annual output of 'Stone Miscellaneous' from Pakistan for the four years ending 1950 was 231,043 tons, but here again it may be doubted whether the returns are really complete, for Pakistan as well as India inherited the same obsolete and careless system.

The statistical basis of this valuable branch of the mineral industry is in urgent need of fundamental revision. It is impossible to estimate from the existing returns how much granite or sandstone, to take but two examples, is really raised, or what proportion of either of them reaches the builder or stonemason, or how much

is used for road metal or railway ballast; neither can it be decided what quantity of India's building stones are at present classified under the description 'Miscellaneous Materials'. Without this information, the orderly development of the great resources available is gravely hampered.

ROAD METAL

The absence of stone from the alluvial plains and coastal tracts not only compelled the use of mud and brick in building construction over wide regions, but also raised many problems when railways and, later still, roads capable of bearing heavy motor transport had to be made across them. As long as road traffic was light and confined to the *palki* and *tanga*, the bullock-cart and the pack animal, road surfaces of *kankar* (*guttin*) or of *moorum* were good enough and such materials were generally obtainable without much cost or difficulty. Away from the regions mentioned there are, as a rule, plentiful supplies of rocks suitable for road metal, rail-track ballast, bridges, river training works, concrete aggregate and so forth.

Strange materials have been employed in difficult situations in the past: the roads of Calcutta were at one time metalled with heterogeneous mixtures of stones brought to the port from all parts of the world as ships' ballast; ancient copper slags from Dhalbhum form part of the monoliths in the Kidderpore docks; iron ores made up part of the Grand Trunk Road as it traverses Bihar; manganese ores were broken up for railway ballast in Visakhapatnam (Vizagapatam); bricks from prehistoric cities served the same purpose in the Punjab; bauxite surfaced some roads in Madhya Pradesh, coral reef fragments have been used along the Tuticorin-Pamban coasts, Madras, and, in the Prome division of Burma, roads are soled with fossil wood.

More than sixty years ago, the Geological Survey of India published a list of 'Quarry Stones' summarizing such information as was then available regarding the occurrences in most of the major States, but it was not until 1924, again at the instance of the Survey, that systematic tests of road stones were regularly undertaken in India by the Government Test House in Alipore. To Dr M. S. Krishnan, the present Director of the Survey, we owe a compact summary of the results achieved up to 1935, as well as a concise statement of the practical conclusions to be drawn from them. This study finally decides the relative merits of the many classes of stone available for use in Indian climates, and under conditions of rain and temperature which differ materially from those of Europe and North America. In this summary full details of attrition and other tests are given on samples from 18 quarries in Assam, 12 in Bengal, 82 in Bihar, 24 in Bombay, 50 in Madhya Pradesh, 7 in Madras and Andhra, 29 in the Punjab and North-West Frontier Province, 13 in Rajasthan and Madhya Bharat and 62 in Uttar Pradesh.

The best stones for road-making purposes prove to be the medium- to fine-grained, compact, basic igneous rocks with more or less equigranular texture. Those varieties with interlocking and ophitic structures are the best of all, for they can withstand heavy traffic, while the powder from their wear and tear acts as a binding agent with the tar or bitumen added in the macadamizing process, producing a tough, smooth and durable surface. Over the whole area occupied by the Deccan Trap such rocks are available, and, further, in many parts of the country to the south of the Deccan they are obtainable from the numerous dolerite dykes which penetrate the crystalline floor in many places. Certain types of amphibolites and epidiorites, such as those of the Shillong area of Assam, the Ranchi and Sambalpur districts of Bihar and Orissa respectively, and the Banda district of Uttar Pradesh, are first-class stones, though as they are derived from basic igneous rocks this is not unexpected. The basalts of the Rajmahal Hills which now supply the needs of Calcutta are also excellent stones of their class.

Among the best of the acid rocks are the granophyres and granulites, as well as the medium-grained compact gneisses and charnockites. The coarser-grained acid rocks are not favoured, owing to the tendency of the cleavage of their constituent minerals to open up with changes of temperature. Recent Indian opinion recommends fine-grained basic and acid charnockites in preference to the banded gneisses among which they often occur in south India. All rocks with strongly developed schistose or coarse gneissose structures, as well as markedly porphyritic kinds, are liable to be torn apart and crushed under heavy loads and should be avoided.

Judged from attrition tests alone, quartzites and vein quartz stand high in the list, but in actual Indian practice they have proved undesirable owing to their lack of binding properties. Vein quartz in particular, though often used by the Public Works Department of the past, especially in southern India, owing to its ease of collection and breakage, produces harsh road surfaces, easily disintegrated into loose pieces, the sharp fractured edges of which are ruinous to rubber-tyred transport. Quartzites make good paving and curb stones, a variety from the Bankura district of Bengal being extensively employed for these purposes in Calcutta.

The sandstones and grits, with only about one-third to one-quarter the wearing power of the trap rocks, are used on a large scale in many districts of Uttar Pradesh, Madhya Pradesh and the Punjab, in default of better materials. As their rounded grains are easily pulled away from their surrounding matrix, which as a powder also possesses little cementing value, they are not suitable, as a general rule, for first-class roads bearing heavy traffic.

Limestones, though soft, possess a favourable feature in the natural cementing tendency of their powders; dolomites are not so good in this respect. Mandalay, the chief city of Upper Burma,

in the dry season used to be plagued with clouds of choking dust, as its trams and other traffic disturbed the powdered dolomite of its roads.

In Western Pakistan as in India, the same varied assortment of rocks—the best obtainable in the immediate vicinity of the work—is utilized. Baluchistan has the somewhat inaccessible ultrabasic intrusives of Zhob and south Kalat, the igneous and metamorphic rocks of the western side of the Khojak range between Chaman and Nushki, while to the west of the latter named place, the volcanic rocks of the Chagai district provide first-class road metal and railway ballast. In the Frontier Province there are the acid volcanic rocks of the Karamar range, east of Shahbazghari, in the Mardan district, though softer limestones are used at present. In the Himalayan region of the Western Punjab, hard rocks of any and every kind are often taken from the river beds for road metal and concrete aggregates. The absence of stone from Eastern Pakistan is a matter of some concern, for apart from roads, harbour works, river training schemes and dam projects demand large supplies.

The deltaic districts of the Irrawaddy are devoid of hard stone and the roads of early Rangoon, like those of Calcutta, were metalled with materials brought in as ballast by sailing ships. Upwards of fifty years ago the then Government of Burma opened up large quarries in the Mokpalin area of the Thaton ridge, from which fine-grained, gneissose granites supplied the needs of Rangoon, Insein and other places. A similar rock was removed in large quantities from Kalagauk Island, off the Amherst coast, for the Rangoon River Training Scheme. Several varieties of suitable volcanic rocks exist in Upper Burma, in the Katha, Shwebo and Lower Chindwin districts, and the lavas of Shinmadaung and of Mount Popa were quarried for road construction and maintenance. Limestones, often of inferior quality, are common in eastern Burma, extending from Tenasserim through the Shan States to the frontier districts, while in the absence of better rocks sandstones are quarried in many localities. In the central districts of the dry zone, and also in the Arakan division, the harder members of both the Pegu and Irrawaddy Series are worked, though they are only fit to be used on second- and third-class roads. Laterites are important in Burma both for road surfacing and as building materials for light structures and are so employed in the Hanthawaddy, Prome, Bassein and Amherst districts. The quarrying industry in Burma is of small extent and comparatively recent growth, for outside the large towns wood is universally employed in house-building and metalled roads are few and far between.

BRICK AND TILE CLAYS

Clays obtained from surface earths, and from the alluvium of the river valleys have furnished the raw material for bricks from

the time of the architects of Harappa and Mohenjodaro (2500-1500 B.C.) to the present day. The prehistoric bricks were kiln-burnt, of standard sizes and produced in millions. Their quality is such that 'today trains rumble over a hundred miles of line (between Multan and Lahore), laid on a secure foundation of third millennium brickbats', taken from Harappa for track ballast. The clays used today, especially for the sun-dried or open-burnt brick, are often very impure, resulting in products of inferior quality, but the demands of modern cities are met by brick works equipped with up-to-date plant and usually situated in their immediate vicinity. Such brick-making was often State-controlled; for example, in 1881, the largest brick-field in India was situated at Akra near Calcutta. It was the property of the Government, with an output of 20 to 30 million bricks annually, which were supplied to the consuming departments at fixed rates and to the outside user at somewhat higher ones. Similarly, for a number of years the biggest brick-field in Burma, again owned by the Government, lay just outside Rangoon, where clays of Irrawaddian age were excavated mechanically and machine-made bricks produced in great numbers.

The raw material of the numerous brickworks which exist today up and down the Hooghly and along its channels comes from the older argillaceous deposits of the river itself, or from the fresh silts of the flood seasons, often collected in troughs specially designed for the purpose. Bricks, roofing tiles, of both the flat and locking patterns, hollow building bricks for internal walls and terracotta wares of various descriptions, are all made on a large scale for the local markets. There are no statistics of this important clay-using industry though it is known that the total annual output is very large.

The tile industry of the West Coast, started by the Basel Mission about 100 years ago, at Mangalore, and using the clays of the Netravati river, gradually spread as suitable silts came to be found in the Gurpur and other rivers and backwaters, until it now extends along much of the Malabar Coast and further inland. Its chief centres, besides Mangalore, are around Calicut, where the Beypore river deposits supply the raw materials, Palghat and other places. By 1933 there were 52 tile-works in operation under the Indian Factories Act alone, and by 1950 this number had increased to 76 factories, many of them equipped with modern mixing mills, presses, driers and continuous kilns. Locked tiles of the Marseilles pattern are a speciality of Malabar, but bricks, pipes and other products are also made. A steady local demand exists and the tiles, which are of excellent quality, finish and appearance, are familiar objects in southern India, Bombay, Ceylon and Burma; in addition a large export trade has been built up with Malaya, Kenya and Australia.

The average number of tiles exported to foreign countries from the Madras State, annually, over the five years ending 1931-2, was 8,153,281, valued at Rs 4,54,385, and formed over 99 per cent of

India's total exports of such goods. In addition to this, there was a coastwise trade amounting to an annual average of 39,410,689 tiles and Rs 16,44,459. No further details of the foreign trade are available until the quinquennial period ending 1949-50, when the annual average had risen to 22,103,009 tiles and the value to Rs 35,40,795. The figures for the coastwise trade are no longer classified separately. Thus, though the statistical history of the trade is unsatisfactory and incomplete, sufficient is known of it to demonstrate how much can be done with such a common mineral as clay, provided high standards are set and maintained and every advantage taken of new technical developments as they appear. It is an encouraging example to other branches of India's ceramic and refractory industries.

A somewhat bigger, red, vitreous, locking-pattern roofing tile is made on a large scale at the Durgapur brick and tile works of Burn & Co. Ltd, founded in 1900, on the Raniganj coalfield. To-day these works can produce 50,000 tiles a day, and are stated to be the only ones in India manufacturing vitreous tiles and bricks from clays with the low vitrification point of under 1000° C. The clays themselves are red, white or cream-coloured varieties included in the sandstones of the Durgapur Beds of the Raniganj coalfield and are of post-Panchet age. It has been suggested, however, that their upper horizons may be related to the laterites of the neighbourhood. Besides roofing and flooring tiles and similar products, machine-made, wire-cut, engineering bricks are made from these Durgapur clays. Such vitrified, non-porous bricks are employed in situations where great mechanical strength and accurate dimensions are required; thus they go into the foundations of large buildings, floorings and so on; millions of such bricks have been used in the construction of India's iron and steel works and other heavy industrial undertakings. Acid-proof bricks are also made at the same works.

Facing bricks have to be uniform in shape, size and colour and should also possess unusual strength and weather resistance. By making use of mixtures of various clays, Burn & Co. and the Bengal Firebrick Syndicate of Kulti turn out blue facing bricks equal in every way to the well-known Staffordshire blue brick. An example of their use may be seen in the King George V docks at Calcutta. Terracotta facing bricks for ornamental purposes are also made from the Durgapur clays and they decorate many of the older buildings in Calcutta.

Bricks and tiles are made from argillaceous alluvium at many other centres in India and Pakistan, and while their products do not compete, as a rule, with those of Malabar and Bengal, they suffice to satisfy local demands in other regions. Complete lists of such works are not available, but, as examples, those of Kanpur in Uttar Pradesh, Bagra in Madhya Pradesh, Rajahmundry in Andhra and Jeypore in Orissa may be mentioned. At the Jeypore works roofing and flooring tiles, vitrified bricks, drain-pipes,

vases, flowerpots and terracotta wares are made from mixtures of alluvial clays with residual varieties derived from the weathering of charnockites.

The following table illustrates the composition of some typical clays of low fusibility used in brick manufacture.

COMPOSITIONS OF CLAYS OF LOW FUSIBILITY

LOCALITY	SILICA	ALUMINA	FERRIC OXIDE	LIME	MAGNESIA	ALKALIS	LOSS	AUTHORITY
Raniganj ..	62.22	24.42	2.44	1.20	0.44	0.27	9.16	Bates
Durgapur	61.70	22.89	6.61	0.54	0.62	1.20	6.52	"
Jabalpur ..	60.56	27.52	1.44	0.65	0.14	0.60	9.32	"

SLATES

Slates are quarried at many places in the outer Himalayas of Kumaun, Garhwal, Kangra and Chamba, and good roofing materials are obtainable locally for the hill towns and villages. The slates of the Dhauladhar Range were known to be of first-rate quality as early as 1860, and, according to H. B. Medlicott, the fissility of the material is all that need be desired; moreover, it dresses easily and can be procured in ample sizes. It is an almost pure siliceous rock of pale grey colour, but, at the same time, not so fine in its minute texture as the well-known Welsh slate and accordingly not applicable for some of the purposes for which the latter is used. The quarries of the Kangra Valley Slate Co. Ltd are at Kunyara in the Dharamsala district of the East Punjab. D. P. Chandoke published an account of slate quarrying in this region in 1933, and states that the rocks concerned are members of the Chail formation. The slates are grey or greenish-grey in colour, of a siliceous character, and yield fairly good roofing materials. Their attractive tint does not fade even after long exposure and they possess no mineral constituents which weather easily. Slate quarries are also in active operation near Pandoh and in the Chichot *tahsil* of the Mandi district of Himachal Pradesh.

Attock slates have been worked in the Nowshera *tahsil* of the Peshawar district of Pakistan for the past 30 years, for use as roofing and flooring materials, as well as for the falls of irrigation canals, but they do not split easily into thin slabs of even thickness.

The Ajabgarh series of rocks which lies at the top of the Delhi System of Purana age, in north-east Rajasthan and adjoining areas, yields slates which are quarried in the vicinity of Rewari, Gurgaon district, East Punjab. A. M. Heron states that they are really hardened shales rather than true slates, furthermore, there are frequently thin films of iron oxide along the bedding planes, which

render the slabs difficult to cut and cause them to wear unevenly, but the Kangra Valley Slate Co. Ltd has worked an excellent band at Kund in this district since 1867, which is free from this defect and gives smooth, fissile, single-coloured and even-textured slabs, and from them slates of all sizes down to one-sixteenth of an inch in thickness are said to be obtainable. Many other marketable varieties of slate are made here in addition to roofing materials, including electrical switchboards, table-tops, shelves, flooring slabs, school slates and blackboards. In addition to the Company mentioned, a number of smaller concerns operate slate quarries in the vicinity of Kund.

Within the sedimentary rocks of Archaean age in Bihar slates are common enough, but they are usually too soft and brittle to be useful. An exception exists in the Kharakpur hills of the Monghyr district, where slates have been known since the middle of the nineteenth century and were probably worked on an extensive scale much earlier. The rock is a slightly metamorphosed phyllite, probably of Dharwarian age, which is readily fissile along its lamination planes. It is quarried nowadays in the neighbourhood of Dharhara, and while it does not give the best varieties of roofing slates, fine slabs are obtainable which have their special roofing uses, as well as flooring squares, switchboard slabs and children's slates. A certain amount of slate quarrying has also been done in Singbhum, to the south-east of Bhitari and near Buhuta.

The manufacture of school slates was first started in 1918, at Markapur in the Kurnool district of Andhra, and of the 200 or so small factories now at work in India producing these articles, some 150 of them are located in this district, the main centres being at Markapur, Cumbum and Gajjalakonda, where the Cuddapah formation contains good slaty bands. This particular slate-bearing belt of the Kurnool and Nellore districts of Andhra extends from Chinnaobanayanipalle, about five miles east-south-east of Cumbum, in Kurnool, to beyond Anantavaram in the Markapur taluk of the same district, and thence across the Venkatagiri area of Nellore district, a total distance of more than 24 miles, with a width of 2 miles. Certain bands at Markapur yield large slabs of high-grade slate suitable for electrical work.

Slate makers in the Bijawar district of Bombay obtain their supplies of stone from quarries at Henemnari and Kaladgi, where there are rocks of the same age and character as the Cuddapahs of Andhra. Many other occurrences of slate have been noted from time to time in other parts of India and Pakistan, and in various geological divisions of the older sedimentary rocks, such as the Champaner Beds of Baroda and the Bijawar System of central India. Noteworthy are the black slates of Mohri Dor, in the Gulmarg hills of Kashmir; the phyllitic varieties of the older Palaeozoic rocks of the Banihal neighbourhood, also in Kashmir; the outcrops along the Aglar valley in Tehri Garhwal, and those of the Chitli

neighbourhood in the Almora district of Kumaun; the smooth, easily splitting slates of the Yellandu taluk, Hyderabad, and the abundant examples in the Axial rocks of the Naga Hills of Assam.

The manufacture of slate pencils was started in this country at Piplia, in the former state of Gwalior, and in Mysore, about 1930, spreading thence to Markapur and other places in the Kurnool district of Andhra a few years later. The second world war stimulated the growth of the slate and slate pencil industry in India, so that today not only are internal needs satisfied but an export trade has been established with Ceylon, Burma, Malaya and South Africa. The present estimated annual production is of the order of $3\frac{1}{2}$ crores of school slates and 20 crores of slate pencils.

Such statistics of slate quarrying as are available show that for the decade ending in 1938, the average annual production was about 10,000 tons. By 1949, this had doubled to 20,323 tons, valued at Rs 9,76,320, and of this total 60.4 per cent came from the quarries in the East Punjab, 12.7 from those of Andhra, 11.6 from Bombay, 7.8 from Bihar, 6.6 per cent from Himachal Pradesh and the remainder from Madhya Bharat.

LIMESTONES

Limestones are the chief representatives of the great group of calcareous rocks and consist chiefly of calcium carbonate, which in the pure, crystalline condition forms the rhombohedral mineral, calcite, or its orthorhombic variety, aragonite, both of which have the same chemical composition, CaCO_3 . Crystals of calcite of extreme purity and transparency are known as Iceland Spar, and their strong double refraction is utilized to obtain polarized light by means of the Nicol prisms of petrological microscopes, colorimeters, photometers, saccharometers and other optical instruments. Limestones, however, are seldom pure and usually contain sandy, argillaceous and ferruginous constituents. Magnesium carbonate too is often present, generally in the form of the double carbonate, dolomite, $\text{CaCO}_3 \cdot \text{MgCO}_3$, and limestones containing appreciable quantities of this compound mixed with the calcite are known as dolomitic limestones. Limestones that have been metamorphosed, either dynamically or by contact with igneous intrusions, become highly crystalline, lose all traces of their organic origin, and are then referred to as marbles.

Other varieties to be included here are chalk, marl, *kankar* and tufa. Chalk is a white, extremely fine-grained limestone, sometimes quite soft and friable, at other times hard and compact. Hard chalk has the same applications as other limestones in the manufacture of lime and of Portland cement. The whiter varieties are very pure and contain from 96 to 98 per cent of calcium carbonate; they are largely composed of the microscopically small remains of foraminifera and broken shelly fragments. Chalk is one of the

sources of whiting, a term which is also applied to finely pulverized white limestone, or marble, and to lime. In India whiting is made by crushing suitable varieties of Porbandar Stone and of the Marble Rocks of Jabalpur, Madhya Pradesh, which are then marketed as extenders for the paint trade and as fillers for textiles, paper, rubber, soap and toilet powders. Other special uses of chalk include putty making and writing materials in the form of white and coloured crayons; it also enters into the composition of some fertilizers, into some ceramic mixtures, on account of its fluxing properties, and into many other chemical and industrial processes. Chalk, in the form of whiting, is a colour wash of universal use and is the basis of the distempers, calcimines and water paints. The purest kinds are termed Paris White in the colour trade. Whiting is also made in India by crushing calcite obtained from veins of hydro-thermal origin in the Deccan Trap of Nawanagar and Porbandar in Saurashtra whence over 10,000 tons have been won since 1945. The production for the three years 1950-2 was 1,860, 1,445 and 2,609 tons respectively. The veins make and break, ramify and coalesce again, so that in places they can be traced intermittently for miles but the workings do not extend much more than 10 to 20 feet below the surface. The best-known localities are in Nawanagar where the deposits of the Panchkoshi, Khambalia, Lalpur, Kalawad, Vantia and Kalyabpur taluks in Halar district are worked by the Jamnagar Minerals Development Syndicate. An average of three analyses of the clean crude mineral shows calcium carbonate 96.49, magnesium carbonate 2.59, combined oxides of aluminium and ferric iron 0.32 and silica 0.30 per cent. After sorting into the three qualities of 'best white', 'white' and 'grey-white', the mineral is ground to 200-300 mesh in a Raymond fine roller mill at Jamnagar and marketed as whiting in Bombay, Calcutta and other cities, where it is doubtless employed for one or other of the purposes already mentioned. Calcite is also worked near Ingorala in Amreli, and Ramgadh in Jungadh, while numerous occurrences have been recorded in the Gir Forest and at Bhetakadi and Bapodar in Porbandar by S. Krishnaswamy, who also thinks that some of the Ramgadh veins might yield small amounts of crystals transparent enough for optical purposes. The mineral is also quarried in the Anantapur district of Andhra and in Jaipur and Udaipur in Rajasthan.

Marl is a term which has been used to include many kinds of clay containing carbonate of lime, but it should be reserved for those in which the calcareous matter ranges from 20 to 50 per cent. Marly limestones are often termed marlstones.

The word *kankar* originally described any form of gravel, whether the rock fragments of which it was composed were rounded or not, but its meaning is now restricted, at any rate amongst Indian geologists and civil engineers, to those small, irregular concretions of

carbonate of lime, which are so widespread throughout the surface deposits of India, parts of Pakistan and some regions in the dry zone of Burma. The commonest forms are small, uneven nodules, from half an inch to three or four inches in diameter, composed of fairly compact carbonate of calcium within, and a mixture of this compound with clay on the outside. More massive varieties frequently fill cracks and are found occasionally as ill-defined beds in the older alluvium. Such block *kankar* has been employed as a building stone and was used, for instance, in connexion with the Ganga canal works.

Closely related to *kankar* are the travertines or calcareous tufas found in or near streams in the sub-Himalayan region and elsewhere, in localities where the waters carry much carbonate of lime in solution. Large blocks of this material of pale grey or dirty white colours may then choke the streambeds, or form the matrix of recent conglomerates, the pebbles of which have been brought down by the streams themselves. In the karstic regions of the Shan States of Burma such deposits are very prevalent, often forming dams or natural weirs, from a few inches to six feet or more in height, extending across even large rivers from bank to bank, and as level along their tops as though built by human agency. Scarped cliffs and precipices of limestone are often festooned with thick curtains of travertine, and where conditions have been favourable such masses may extend completely across deep gorges and form natural bridges, similar to the one which carries the railway viaduct at Gokteik, between Maymyo and Lashio. In the hilly regions throughout India, such tufa deposits, though only of limited extent as far as total tonnage goes, are a convenient and common source of raw material for the local lime kilns.

When limestone is heated to temperatures of 800° to 1000° C., in kilns from which its released carbon dioxide can escape, the oxide, CaO , or quicklime, is obtained in the form of hard white lumps. When heated very strongly, as with an oxyhydrogen blow-pipe, it incandesces and glows with an intense white light, a property utilized in forms of 'limelight' illumination. Pure limestones on calcination yield a rich or 'fat' lime, which should only contain about 5 per cent of extraneous matter; impure limestones give a poor or 'lean' lime, which may contain from 10 to 30 per cent of foreign substances. Quicklime is a very reactive substance and has a great affinity for water, of which it can absorb about one-quarter of its own weight, a process accompanied by the evolution of heat and the breaking down of the original lumps into a white, amorphous powder, calcium hydroxide or slaked lime, $\text{Ca}(\text{OH})_2$. This, made into a thick, plastic paste with sand and water, is the common mortar of the builder which sets on exposure to the air by loss of water, and gradually hardens through the absorption of carbon dioxide from the atmosphere with the formation of calcium carbonate once more. Other types of mortar are made by adding

varying quantities of cement to the lime-sand-water mixture. Sand-lime bricks possess this sort of composition. Plasters used for walls and ceilings are mixtures of lime paste, sand and hair.

Hydraulic limes are made by burning impure clayey limestones which contain enough silica and alumina to form unstable calcium silicates and aluminates, at the same time leaving sufficient uncombined lime present to permit of slaking. Such limes have the property of setting under water and becoming very hard in a few days. Limes made from *kankar* often possess hydraulic properties.

Portland Cement is discussed separately, and here it is only necessary to mention that it is made by roasting intimate mixtures of limestone (or chalk) and clay in long, sloping, slowly rotating cylindrical furnaces.

Limestone and dolomite are the chief fluxing agents in the smelting of iron ores and enter into many other metallurgical operations, such as the dolomite linings of convertors and furnaces in which steel is made by the basic process.

Lime has a fundamental role in agriculture and horticulture and the liming of land is one of the oldest methods of improving the soil: it renders clayey soils more friable and easier to work, besides promoting drainage; loose, sandy ones more compact and better able to carry crops in dry weather. It accelerates the decomposition of both organic and inorganic substances by chemical action and in so doing liberates plant foods; it checks plant diseases and is injurious to soil pests; it neutralizes the acidity of sour soils and so improves their yielding power.

Many industries require large quantities of lime, including those concerned in paper-making, leather-tanning, glass manufacture and sugar-refining. It is employed in the manufacture of bleaching powder, caustic soda, and sodium carbonate, in water-softening and in the preparation of calcium carbide, CaC_2 , from which the fertilizers calcium cyanamide, CaCN_2 , and nitrolim, a mixture of carbon and calcium cyanamide, are made. Another well-known fertilizer, nitrochalk, is a mixture of ammonium nitrate and chalk. It has been said that there is virtually no chemical process wherein lime is not used at some stage, either directly or in the manufacture of the reagents themselves.

Calcium itself is a soft, silvery white metal obtained by the vacuum reduction of lime with aluminium or silicon, or by the electrolysis of its fused chloride. It has the low density of 1.55, oxidizes in moist air, reacts with water, liberating hydrogen, and must be stored in moisture-proof containers. One pound of calcium produces about 9 cubic feet of hydrogen from water. It is marketed in the form of $4\frac{1}{2}$ lb. cast ingots, 100 lb. cast billets, and as extruded sticks. It is employed to reduce refractory metallic oxides such as those of chromium, thorium, uranium, titanium, vanadium and zirconium; to dehydrate absolute alcohol, ethylene glycol, petroleum fractions, etc.; to desulphurize petroleum; to purify argon and

helium, and to remove the last traces of oxygen and nitrogen from vacuum systems. Calcium is used in metallurgy as a deoxidizing, desulphurizing and degassing agent of steel, copper, nickel and the non-ferrous alloys, though in the case of high-grade steels, calcium silicide, made in the electric furnace from mixtures of calcium carbide, quartz and coke, is preferred. Calcium forms alloys with many other metals: lead alloys, for instance, containing only from 0.1 to 0.4 per cent of calcium are used for cable sheaths, bearing metals and the plates of accumulators. The addition of only 0.1 per cent of calcium into the lead of such storage batteries produces an alloy equivalent to the 9 per cent antimony alloy, which, moreover, is more resistant to sulphation, has an electrical conductivity some 20 per cent higher and retains its charge longer. For most of these details regarding the metal itself we have to thank Dominion Magnesium Ltd, of Ontario, Canada, manufacturers of calcium, barium and strontium.

Other important salts of calcium are gypsum, calcium sulphate, CaSO_4 ; fluorite, calcium fluoride, CaF_2 ; apatite, a fluorophosphate, $3\text{Ca}_3\text{P}_2\text{O}_8 \cdot \text{CaF}_2$ (or CaCl_2) and the fertilizer 'superphosphate', all of which are dealt with separately. Calcium chloride, CaCl_2 , is a valued drying agent in chemical laboratories, is used in civil engineering as a road stabilizer and as an early setting agent in concrete mixes. Calcium bisulphite, $\text{Ca}(\text{HSO}_3)_2$, is extensively employed for dissolving the lignin of wood pulp in the manufacture of paper.

Limestones are present in most of the geological formations of India, West Pakistan and Burma, though in some of them they are rare and in others impure and only of poor grade. They range in age from the marbles of the pre-Cambrian crystalline rocks to the *kankars*, travertines and coral reefs under active formation today, but the largest supplies are to be found in the Cuddapah, Vindhyan and Tertiary Systems. From a regional point of view Assam, Bihar, Andhra, the Uttar, Vindhya and Madhya Pradeshes and Hyderabad possess great resources; Western Pakistan is favoured with practically unlimited reserves of many kinds, and while the lower Irrawaddy valley of Burma is deficient, limestones abound in the hilly regions of Tenasserim, Karenni and the Shan States to the east and north.

The average annual recorded production of limestone, dolomite and *kankar* for the whole of undivided India increased from 3,083,000 tons, valued at Rs 50,43,000, over the period 1923-8, to 7,688,000 tons, valued at Rs 1,16,97,000 for the three years ending 1946. Over the quinquennium ending in the same year, 1946, i.e. the last complete year before separation took place, the annual production averaged 6,729,000 tons, of which limestone accounted for 4,283,000 tons, or 63.7 per cent; *kankar* 2,359,000 tons or 35 per cent; and dolomite 87,000 tons, or 1.3 per cent. Over 96 per cent of the *kankar* was dug in Uttar Pradesh where it is widely used as

a road dressing, the remainder coming from the Punjab, Rajasthan and Mysore. More than 98 per cent of the dolomite was quarried in what were at that time the Eastern States. The distribution of the 4,283,000 tons of limestone was as follows, the figures being given in thousands of tons and percentages of the total: Bihar, 808 (18.8); Eastern States, 807 (18.8); Punjab 583 (13.6); Central Provinces 482 (11.3); Assam 386 (9.0); Sind 360 (8.4); Madras, 350 (8.1); Rajputana 281 (6.5); Gwalior 87 (2.0); Hyderabad 68 (1.6); Central India 51 (1.2), with the remainder in smaller quantities from Mysore, United Provinces and Bombay. Since the division of India in 1947, the average annual production of limestone, *kankar* and dolomite, over the three years ending 1949, for the Indian Union alone, totalled 4,650,000 tons, valued at Rs 1,63,87,398, of which limestone accounted for 3,797,318 tons, or 81.6 per cent; *kankar*, 788,654 tons or 17 per cent, and dolomite 64,044 tons or 1.4 per cent. Some idea of the present distribution of limestone production can be gained from an analysis of the production total of 4,101,467 tons quarried in 1949: to this quantity the percentage contribution of the various States was as follows: Orissa 22.5 per cent, Bihar 18.7, Madhya Pradesh 17.6, Madras and Andhra 16.7, Madhya Bharat 5.0, Hyderabad 4.9, Vindhya Pradesh 3.1 and Saurashtra 2.6 per cent, with the remainder drawn in smaller amounts from the Eastern Punjab States, Rajasthan, Uttar Pradesh, Mysore, Bombay, West Bengal, Ajmer-Merwara and Assam. The returns for 1949 also include the production of 40,539 tons of lime, more than half of which was made in Assam and most of the remainder in Madras including Andhra and Madhya Pradesh. In Pakistan, over the four years ending 1950, the average annual production of limestone was 351,400 tons, valued at Rs 3,95,136, and of this 57.2 per cent was contributed by the West Punjab and 42.8 per cent by Sind.

In view of the greatly increased demands for limestone by post-war developments in irrigation, hydro-electric schemes and industrial projects generally, the Geological Survey of India has of late years made special investigations into the limestone resources of the country, with the result that voluminous records now exist as regards both their quantity and quality. It is impossible even to summarize these adequately in the space available here, but it is hoped that the following notes on the more important occurrences, together with others given under **DOLOMITE** and **CEMENT**, will convey an accurate general impression of this important mineral commodity. They are arranged in the order of production of the various States for 1949, given in the previous paragraph.

Commencing with the limestones of Orissa, as they supply most of the country's requirements at the present time, they are bands of calcitic marble, overlying the dolomites of the Birmitrapur Stage of the Middle Dharwarian, Gangpur Series, in the district of Sundargarh. These marble zones are found in both the northern and

southern limbs of a great anticlinorium, described in further detail under DOLOMITE, and have been worked at many places in the southern limb lying within short distances of the Bengal-Nagpur railway, which conveniently runs more or less parallel to it. From 1898 until about 1922, Bisra on this railway was the most important lime-making centre in India, obtaining its supplies of raw stone from the southern limb, but activities were then transferred to Birmitrapur on the northern limb, where, as Dr M. S. Krishnan's elucidation of the geological structure of this complicated region has shown, the limestone (and dolomite) bands are of greater width than elsewhere, except in the folds at the eastern end of the anticlinorium, where, however, the marble zone is greatly disturbed. The reserves of limestone are very large, and in the Birmitrapur area alone Dr Krishnan, in 1937, estimated that some 27½ million tons of first-grade rock, fit for metallurgical purposes, and 68½ million tons of second quality, suitable for lime-making, were available. The leading producers are the Bisra Stone Lime Co. Ltd, at Birmitrapur, whose quarries are equipped to handle 2,500 tons daily, and there are 16 lime kilns with a daily capacity of some 220 tons of lime. The great bulk of the output is, however, railed to Jamshedpur and elsewhere for use as a flux in the iron and steel industry. There are of course many other localities, on extensions of these two zones, where limestones of similar qualities have been investigated. The long belt of limestone at Lanjiberna on the southern limb near Rajgangpur is now quarried for Portland cement manufacture. Outside the Gangpur area limestones of Cuddapah age are known at numerous places in the Sambalpur district, though as a rule they are somewhat argillaceous, siliceous or dolomitic, but in the Koraput district there are some bedded deposits of better grade material of the same geological age, near the Sabarai river, some three miles west of Kottametta.

Bihar is the second largest limestone-producing State and there is a reference to the quarries at Rohtasgarh, in Shahabad, as early as 1847; in 1869 there was a brisk trade in the lime made in this neighbourhood, which was brought by boats down the Son river and thence to the towns up and down the Ganga (Ganges). The well-known Rohtas Limestone forms the topmost stage of the Semri Series, of the Vindhyan System, cropping out along the left bank of the Son, in the lower slopes of the Kaimur scarp from Vindhya Pradesh in the west, through Mirzapur into Shahabad. In Bihar alone the length of its outcrop is over 45 miles, and it is extensively quarried for cement manufacture from Chunhattar in the west, where it has a minimum thickness of 500 feet, to Ramdhira-on-Son in the east. The Rohtas Stage as a whole contains alternating bands of fairly pure and less pure limestones, together with calcareous shales and shales of normal types. The horizons of the best limestones lie between 250 and 500 feet from the top of the Stage, and these may contain from 80 to 95 per cent of calcium

BUILDING MATERIALS
ANALYSES OF ORISSA LIMESTONES

DISTRICT	LOCALITY	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Loss on Ignition	REMARKS
Sundargarh	Birmitrapur	2.83	0.62	0.55	49.39	3.26	41.89	Mean of 8 analyses by G.S.I.
"	"	3.36	0.64	0.91	50.55	2.09	41.43	Open-hearth Grade. Bird & Co.
"	"	4.41	0.72	0.99	49.77	3.18	41.20	Blast Furnace Grade. Bird & Co.
"	"	10.10	1.60	1.30	45.90	3.30	37.70	Ordinary Grade. Bird & Co.
"	Hathibari	3.72	0.87	0.94	49.43	3.41	41.53	Tata I. & S. Co.
"	Lanjiberna	5.02	1.34		49.95	2.06	40.79	Mean of 6 analyses by G.S.I.
Sambalpur	Dungri	14.13	1.08	1.75	45.84	1.56	..	Mean of 13 analyses by G.S.I.
Koraput	Kottametta	1.84	1.24		53.36	0.59	..	Analysis by Seshadri, T. S.

ANALYSES OF LIMESTONES FROM BIHAR

DISTRICT	LOCALITY	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Loss on Ignition	REMARKS
Shahabad	Chunhattar	10.84	0.80	1.14	46.48	1.86	38.64	Alkalis 0.24. Rohtas, S.V.P.C. Co.
"	"	9.54	2.00	0.92	46.74	1.60	38.70	Alkalis 0.50. Average. S.V.P.C. Co.
Hazaribagh	Bandu-Basaria	11.27	0.95		47.67	0.72	..	Mean of 8 analyses. Archaeana.
Palamau	Khalari	15.40	2.20	1.10	44.00	2.80	34.40	A.C.C. Ltd
Singhbhum	Kolhan Limestone	8.29	0.88		50.58	0.53	39.78	Mean of 60 samples

carbonate, 2 to 3.5 per cent of magnesium carbonate, 3 to 12 per cent of silica and 1.5 to 3 per cent of combined alumina and ferric oxide. Out of 595 analyses of Rohtas Limestone, kindly supplied by the Sone Valley Portland Cement Co. Ltd, 65 (i.e., 11 per cent) had 0.40 per cent of ferric oxide, or less than this amount. A few selected bands might provide material for use in the glass industry. Discontinuous bands of crystalline limestone of Archaeana age are also to be found in Bihar, from west of Panchet Hill in Manbhum to south-west of Daltonganj in Palamau. The bands to the west of Ramgarh, in Hazaribagh, are not so siliceous as some of those further to the east and often contain abundant stone suitable for cement manufacture. They have been quarried for lime burning in the Bandu-Basaria area of Hazaribagh and about Dundu Ray in Ranchi;

and for cement manufacture at Khalari, in Palamau. The Kolhan Series of Singhbhum contains a limestone zone, immediately overlying its basal sandstone, which is of variable thickness and quality (up to a maximum of 40 feet). It has been quarried since 1947 near Chaibasa by the Associated Cement Co. Ltd, and is traceable for about 30 miles from Chaibasa to Jagannathpur. The limestones of Gondwana age occurring within the Lower Panchets, near Baghmara in Manbhum, though used long ago as flux-stones at the Kulti iron works, are of little economic importance today.

The limestone production of Madhya Pradesh now approaches closely to that of Bihar, and, as in that State, the greater proportion is derived from strata of Vindhyan age. In the Jabalpur district limestone quarrying has been an established industry of the Katni-Murwara area since 1872, and there are important workings at Tikaria, where the Vindhyan limestones are capped by laterite and fullers' earth, at Tikuri, at Murwara itself, where the upper limestone bed contains two separate high-grade bands, 15 and 9 feet thick respectively, and in the Jukehi-Kaimur region, east of which the limestones extend into Rewa of Vindhya Pradesh, along the base of the Kaimur scarp. The quarries of the Associated Cement Co. Ltd, all of which are in the Semri Series of the Vindhyan, are situated at Barapara, Khalwara, Mehgaon, Katni and Kymore. The Lameta Series comprises limestones, sandstones and shales of freshwater origin which are found below the Deccan Trap at numerous localities in the Nagpur, Amraoti and Chanda districts, but they are very variable in composition and usually contain cherty segregations; along the outer Chikalda range, however, between Belkher and Bairam Ghat, in Amraoti, they are locally pure enough to be burnt for lime. In Chanda district, the Vindhyan limestones appear again, a fairly accessible outcrop being at Kandara, six miles north of Warora; they belong to high-grade types, often with only 2 per cent of insoluble matter and 1 to 2 per cent of combined alumina and ferric oxide. Limestones of Cuddapah age are of importance in the eastern districts of Madhya Pradesh, and have been traced as discontinuous outcrops for a distance of 80 miles, between Barondha and Sukhri, in the Raipur-Drug region. P. K. Chatterjee estimated reserves of nearly 21 million tons at a number of localities examined by him in Drug, with a further 17½ million tons in Raipur district. These stones are, as a rule, low in magnesia and high in insoluble contents, suitable for cement manufacture but of little use as metallurgical fluxes. Similar rocks occur in Bilaspur between Darrabhata, on the western bank of the Hasdo river, and Akaltara, where they are extensively quarried. Very large quantities are available, the Mohtara locality alone having some 10 million tons of good flux-stone. The quarries of the Tata Iron & Steel Co. Ltd, which have supplied limestone for the Jamshedpur works since 1919, are at Baraduar. The insoluble

contents of this variety average about 6 per cent. In the eastern part of Nandgaon, which lies to the west of the Drug district, similar gently dipping limestones stretch for nearly 30 miles between Khalewa and Arjuni, and the reserves both here and in other localities must be very considerable. In the Berar region, in the south-west corner of Madhya Pradesh, there are limestone beds of wide extent in the Wun *tahsil* of the Yeotmal district, extending to the south-east across the Penganga river into the Adilabad district of Hyderabad, but while some of these are low in magnesia, others are distinctly dolomitic, ranging in places into true dolomites, as on the summit of Gowari Hill.

ANALYSES OF LIMESTONES FROM MADHYA PRADESH

DISTRICT	LOCALITY	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Loss on Ignition	REMARKS
Jabalpur	Tikaria	2.08	1.12		53.87	0.72	42.10	Vindhyan stone. Cook & Sons
"	Murwara	1.84	0.46		52.92	1.01	..	Vindhyan stone. Mohar Singh
"	Barapara	5.48	1.74	0.90	49.80	1.26	40.40	Vindhyan stone. A.C.C. Ltd
Drug	Kumari	9.97	4.22		40.99	2.25	..	Cuddapah stone. Mean of 24 analyses
Bilaspur	Champa	8.02	1.41	1.56	43.40	1.99	..	Cuddapah stone. Mean of 22 analyses
Yeotmal	Gowari	3.76	0.35	0.65	52.61	0.20	42.32	....

In Andhra and Madras crystalline limestones of Archaean age are known in the districts of Visakhapatnam, Nellore, Tiruchirappalli, Salem, Coimbatore (where they are utilized by the cement works at Madukkarai), Madurai (where they have been used as road metal), Ramanathapuram and Tirunelveli. At Talaiyuttu, in the last-named district, they contain about 1.2 per cent silica, 0.3 per cent combined alumina and ferric oxide, 1.2 per cent magnesia and over 53 per cent lime, and are being taken for cement manufacture by India Cements Ltd. Some of the crystalline limestones of these parts of southern India are of a dolomitic character. The Narji Limestones are well displayed on both sides of the Krishna river, in the Palnad region of Guntur, and in the Jaggayapeta-Mutyala area of the Krishna district. In the former they are quarried at Sitarampuram by the Associated Cement Co. Ltd, while the Andhra Cement Co. Ltd has quarries at Nadikude and Kesanapalli, as well as at Ravirala and Jayantipuram in Krishna. Outside the leases of these concerns there are, according to M. S. Rao, another 17

million tons available around Pidugurala alone, in Guntur. The Narji Limestone, typically a fine-grained grey or buff stone, lies towards the base of the Kurnool Series, itself overlying the Cuddapah System, and possibly the equivalents of the Lower Vindhya of central India. The Vempalle Limestone of Lower Cuddapah age extends in a wide arc, from 1 to 4 miles wide, for over 175 miles, across the Cuddapah and Kurnool districts, from near Cuddapah town to the neighbourhood of Betamcherla, though much of it is of a dolomitic character. The Narji Limestones follow a straighter trend from a point near Cuddapah, north-west across the two districts, through Banganapalle to the Tungabhadra river and beyond; the reserves of good cement-making limestones are practically unlimited, amounting to 640 million tons in the Kamalapuram taluk and 3,000 million tons in the Jammalamadugu taluk of Cuddapah district; 5,000 million tons in the Koilkuntla, 660 million tons in the Banganapalle, 450 million tons in the Dhone, 1,250 million tons in the Kurnool and 770 million tons in the Nandikotkur taluk of the Kurnool district, according to N. V. B. S. Dutt. Other limestones of younger age than the Narji stone,

ANALYSES OF LIMESTONES FROM ANDHRA AND MADRAS

DISTRICT	LOCALITY	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Loss on Ignition	REMARKS
Salem	Nadanadai, etc.	0.51	0.55	0.33	54.26	8.80	..	{ Archaean stone. Mean of 4 analyses
Ramanathapuram (Ramnad)	Pandalkudi	2.09	0.59	0.64	53.59	0.25	42.47	{ Archaean stone. Mean of 11 analyses
Kurnool	Owkavuku, etc.	11.32	2.27	0.77	47.31	tr.	37.74	{ Narji stone. Mean of 18 analyses
"	Betamcherla	13.86	1.56		46.37	0.56	37.25	{ Narji stone. Mean of 71 analyses
Guntur	Pidugurala-Sitarampuram	13.45	1.93		45.15	1.48	37.64	{ Narji stone. Mean of 33 analyses
"	Zulakallu	9.06	1.16		47.64	1.38	39.88	{ Narji stone. Mean of 5 analyses
Kurnool	Palkur	0.88	0.70		53.24	2.01	43.34	{ Tufa One analysis
Anantapur	Rameswaraswami	2.68	1.01	0.61	53.03	tr.	42.24	Tufa
Godavari E.	Bhadra-chalam	4.80	2.70		48.14	2.85	..	Kankar

though still within the Kurnool Series, also occur in these same regions. The Vempalle Limestones are found again in the Anantapur district, where, also, the calcareous shales and intercalated limestones of the Cheyair Group have given rise to much *kankar* and tufa, with an average content of 38.85 per cent lime and 8.46 per cent magnesia, over a belt of country some 2 miles wide and 25 miles long, passing through Rayalacheruvu. These tufas are exploited for chemical manufacture. Shelly and argillaceous limestones of Cretaceous age occur in Pondicherry, parts of South Arcot, and in the Tiruchirapalli district where they are actively worked both by the Government of Madras and by various concerns, including the Dalmia Cement Co. Ltd, in the Lalgudi and Perambalur taluks. It remains to mention the inter-Trappean limestones utilized in East and West Godavari for local lime-burning, the sub-Recent shelly beds of Rameswaram and recent shells of the Pulicat Lake in Nellore and of the river beds of Mangalore, and Recent coral reefs in the isles of the Gulf of Manaar, used for the same purpose.

In the northern portion of Madhya Bharat the rocks of the Vindhyan System are again available, particularly where the Bhandar Limestones of its uppermost series are worked at Kailaras and Semai for cement-making. The Nimbahera Limestones are also extensively developed in Mandasor but they are usually rather siliceous, while others of Archaean, Bijawar, infra-Trappean and inter-Trappean ages occur in Nimar, Dhar and Jabua districts.

The Kurnool limestones of Andhra, as well as those of the underlying Cuddapah System, cross the northern boundary of the State into the Alampur taluk of the Raichur district of southern Hyderabad, whence they extend for 150 miles along the north bank of the Krishna, the Cuddapah exposures being continued to the east again by the limestones of the Palnad. The latter are especially prevalent in the Wazirabad-Medlacheruvu region of the Nalgonda district and have been found suitable for cement manufacture. West of the capital, the Bhima limestones emerge from below the Deccan Trap in the valleys of the Bhima and Kagna rivers. They are probably the equivalents of the Kurnool limestones, occupy an area of over 600 square miles and are quarried about Shahabad, in Gulbarga district, both for flooring, roofing and general constructional materials, as well as for cement manufacture. In the belt of Purana rocks comprising the Penganga and Pakhal Series which extends for 200 miles from north-west to south-east, across the north-eastern part of Hyderabad, parallel to the Penganga-Wardha-Pranhita-Godavari rivers, there are many limestone horizons.

In Vindhya Pradesh, limestone supplies are derived from both the Bhandar Stage of the Upper Vindhyan and from the Rohtas Stage of the lower part of the same System. Quarrying is an old-established industry in the Maihar region, where the Bhandar Limestones are exposed over an area of about 370 square miles.

Other outcrops exist around Satna, and the same formation extends westwards for another 50 miles into Sohawal and Nagod. The Rohtas limestones lie along the southern foot of the Kaimur scarp from Bistara to the east of Churhat, a distance of 96 miles.

The sub-Recent 'Porbandar Stone', which derives its name from the port from which it is shipped to Bombay and other places, a limestone of high purity, is the principal calcareous product of Saurashtra. It is composed chiefly of the tests of foraminifera cemented together by calcite and is quarried at Aditania, Bharwada and Bakharla for building stone, chemical production and the manufacture of Portland cement. Similar miliolite limestones have been quarried in the Zalawad district of Wadhan and occur also at Bardia, in Junagadh, Amreli and Babriawad. Recent coral limestones of the margin of the Okhamandel (an enclave of Bombay in Saurashtra) coast are used by Tata Chemicals Ltd at Mithapur.

ANALYSES OF LIMESTONES FROM MADHYA BHARAT, HYDERABAD, VINDHYA PRADESH AND SAURASHTRA

DISTRICT OR STATE	LOCALITY	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Loss on Ignition	REMARKS
Morena	Kailaras	12.26	3.76		46.09	0.39	37.19	{ Bhandar stone. Mean of 6 analyses
Mandasor	Kesharpura	18.74	3.37		41.16	1.89	34.67	{ Nimbahera stone. Mean of 12 analyses
Hyderabad	Gulbarga	10.61	2.62	0.41	47.28	0.94	37.81	{ Bhima stone
Sohawal	Satna	5.26	1.11		51.60	0.43	..	{ Satna Stone and Lime Co.
Maihar	Amelia	1.88	0.43		53.26	1.42	..	{ M. S. & L. Co.
Porbandar	Aditania	4.16	1.50	0.50	51.50	0.60	41.60	{ A. C. C. Ltd
Junagadh	Gorakundi	0.87	0.87		53.73	0.68	43.50	{ Mean of 14 analyses. G.S.I.

Note.—Morena and Mandasor are in Madhya Bharat; Sohawal and Maihar in Vindhya Pradesh; Porbandar and Junagadh in Saurashtra.

In the Eastern Punjab, limestones occur in the outermost fringes of the sub-Himalayas in both Ambala and Patiala. One such occurrence, a band of almost vertical, massive limestone, 50 feet thick, is exposed on the Eastern Ghaggar river just before it leaves the hills near Junpur, whence it has been traced for about three miles. To the south-east of Kalka, intermittently between Malla and Sherla, there are similar deposits of good-quality stone, the estimated reserves of which, according to M. R. Sahni and B. R. C. Iyengar, are of the order of 26 million tons. Limestones of a good grade have also been recorded by G. N. Dutt, in the pre-Tertiary

sequence at Dabsu, Narayangarh *tahsil*, Ambala district. The Malla quarries of the Associated Cement Co. Ltd have been in operation since 1939 and their product is said to be a very compact, thinly bedded, grey to black limestone of the Subathu Series, of Eocene age.

Although the celebrated Makrana marble of Jodhpur yields an excellent lime when burnt, the most important sources of lime in Rajasthan are, as elsewhere, to be found in the limestones of the Vindhyan System, particularly in those of the Nimbahera group, between Chitor in Udaipur and Nimbahera itself, in Tonk; of the Bhandar Series on the Vindhyan plateau about Lakheri, in Bundi; and of the great spread of limestones to the west of the Aravalli range. Many of the Nimbahera Limestones are low in calcium oxide, but certain bands occurring between Julmi and Mailo, and, again, between Nimana and Deoli and extending over a total length of 20 miles, with a thickness of 200 and 250 feet, often show insoluble contents below 16 per cent, lime about 43 per cent and magnesia within 1.1 per cent. From Lakheri, where the Bhandar Limestone is quarried on a large scale both for lime-burning and cement manufacture, its outcrop has been traced to the neighbourhood of Bundi, a distance of 37 miles. Further to the south-east, however, where the same limestone bands occur in the Mukandwara hills of Kotah for a distance of about 34 miles, they are highly magnesian. In Jodhpur, Vindhyan limestones are obtainable in any quantities near Sojat and Gotan. The quarries of the Gotan Lime Syndicate were opened in 1923 and now support a large and thriving industry. Gotan lime with a content of 97.3 per cent calcium oxide, 1.14 insoluble material, 0.35 combined alumina and ferric oxide and 0.90 per cent magnesia, is used extensively in many parts of India.

The zone of the Rohtas limestone exposed in the lower slopes of the Kaimur escarpment, on the northern side of the Son valley, crosses the Mirzapur district of Uttar Pradesh through Silpi and Basuhari, a distance of about 80 miles. In the eastern section of the zone, described as the most promising from the point of view of cement manufacture, individual bands, states Mukti Nath, are from 100 to 300 feet thick and traceable for distances of 50 to 55 miles. Extensive reserves of cement-grade stone are known to exist between Markundi and Pataudh. Parts of the Kajrahat Limestone, which belongs to the Basal Stage of the Semri Series, have been found to be of high grade near Kotah on the Kanhar. In the outer Himalayas of the north-west of the State, limestones of cement grade occur abundantly in the valleys of the Tons, Amlawa and Jamuna rivers and to the south and west of Chakrata. Again, in the hilly country south and west of Mussoorie, a band of micro-crystalline marble of great purity has been followed at intervals for 5½ miles, and contains as a minimum 34 million tons. Limestones low in magnesia but high in silica occur abundantly in numerous

localities, and particularly north and east of Lansdowne and near Dogadda and Manjhola. Several good tufa deposits occur in the Naini Tal and Dehra Dun neighbourhoods, while marlstones, usually less than 4 feet in thickness, exist in shallow depressions under thin covers of alluvium in the districts of Barabanki, Lucknow, Rae Bareilly and Unao.

Archaean crystalline limestones and especially those of the Shimoga, Chitaldrug, Tumkur and Mysore districts, supply the needs of Mysore. Certain occurrences in the Hosdurga and Vobla-pur areas of Chitaldrug and Tumkur, respectively, are known to contain about 50 million tons of stone, averaging 3 to 4 per cent of silica, 49 per cent of lime and 2·8 per cent of magnesia. The flux-stones used in the Mysore Iron & Steel Works come from quarries at Bhadigund, 13 miles east of Bhadravati, while the limestones for the cement works are drawn from the same neighbourhood. Both crystalline limestones and dolomites often give rise to rich deposits of tufa and *kankar* in the districts already named.

ANALYSES OF LIMESTONES FROM THE PATIALA & EAST PUNJAB STATES UNION, THE EAST PUNJAB, RAJASTHAN, UTTAR PRADESH AND MYSORE

DISTRICT OR STATE	LOCALITY	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Loss on Ignition	REMARKS
Patiala	Malla	3·50	1·10	1·10	53·10	1·10	41·20	Subathu stone. A. C. C. Ltd
Ambala	Tundapathar	3·14	1·54		51·64	1·32	41·48	Subathu stone. Mean of 8 analyses. G.S.I.
"	Sherla	4·82	3·84		47·36	2·91	40·77	Mean of 8 analyses. G.S.I.
Bundi	Lakheri	14·34	2·90	1·40	45·02	0·98	35·08	Bhander stone. A. C. C. Ltd
Jodhpur	Sarangwa	7·80	0·02		52·98	0·11	39·72	Archaean stone.
Udaipur	Chitor	15·95	2·66		44·48	0·30	36·05	Nimbahera stone. 17 analyses. G.S.I.
U. Pradesh	Bhatta (Mussoorie)	0·14	0·15		55·14	0·38	43·80	Upper Krol marble. 12 analyses. G.S.I.
"	Tons river	6·68	1·52	1·98	48·76	1·19	39·97	Deoban stone. G.S.I.
"	Doiwala (Dehra Dun)	4·66	1·65		51·14	0·36	41·65	Tufa. Mean of 71 analyses. G.S.I.
Mirzapur	Markundi	8·34	1·12	1·06	48·45	1·08	39·23	Rohtas stone. Mean of 21 analyses. G.S.I.
Shimoga	Bhadigund	2·78	0·90	1·20	50·50	1·91	41·56	Archaean stone. Mysore I. & S. Works

Note.—Patiala is in the Patiala & East Punjab States Union; Ambala in the East Punjab; Bundi, Jodhpur and Udaipur in Rajasthan; Mirzapur in Uttar Pradesh and Shimoga in Mysore.

LIMESTONES OF PAKISTAN

The vast alluvial plain which constitutes the greater part of East Pakistan contains no limestones, and its only cement works, situated at Chhatak, draw their supplies from the Khasi Hills of Assam, a State of the Indian Republic: in striking contrast are the enviable resources of West Pakistan where unlimited quantities of limestone are available in the northern Punjab, the North-West Frontier Province and widespread regions of Baluchistan and Sind. In the Salt Range region of the Punjab three separate horizons are concerned, namely, the thick limestones and marls associated with the Eocene Nummulitic rocks, the Upper Jurassic Limestones and the Middle Productus Limestones of Permian age. The white, light-grey and yellowish nodular and bedded limestones of the Eocene are of great extent; it is indeed possible to walk from the vicinity of Baghanwala, in Jhelum district, westwards and north-westwards along the Range, for about 110 miles, almost without stepping off the outcrop of these 'Sakesar' Limestones, as they are called, and this by no means marks their total limits. They thicken to the westward, from about 100 feet near Ara to 250 feet at Dandot, to 600 at Sakesar and to 700 at Nammal, being about 600 feet thick as they disappear near Jaba, in Mianwali district. These thicknesses include certain underlying calcareous shales and a second limestone band, the Nammal Limestone. All these rocks overlie the Dandot coal-bearing horizon, but beneath it another thick limestone (the Khairabad Limestone) occurs. Thin or absent in the east of the Range, varying in thickness in the middle section, it increases rapidly in a westerly direction and attains over 1,000 feet east of Daud Khel. As a general but not universal rule, these Eocene limestones cap the scarp of the range or lie on the top of the plateau behind it and many of the stones average from 95 to over 98 per cent of calcium carbonate. The fine-textured, light grey, rather flaggy limestones of the Upper Jurassic are only found in the western section of the Salt Range, and are economically important in the Mianwali district alone. They vary in thickness from about 20 to 100 feet. The limestones of the Middle Productus Stage occur within the scarp slopes of the Salt Range from Katha westwards to near Daud Khel, a distance of approximately 65 miles. They are hard, massive, light to dark grey rocks, very fossiliferous at certain horizons. They rapidly thicken to at least 300 feet and cover very wide areas between Nali and Sakesar and further west around Chhidru. In the Nammal gorge they are 450 to 500 feet thick and are quarried for building stones and ballast near the rail-heads of Warcha Mandi and Sanwans. Though they include some partially dolomitized varieties, a very large proportion of the stone is of good quality. All three groups of limestones, with much the same qualities, appear again in the trans-Indus Salt Range, those of Nummulitic and Jurassic age in regular outcrops of appreciably

greater thickness than before, as far south as Mitha Katak and Makarwal, respectively. The Middle Productus group occurs in the slopes north of Kalabagh and in those of the bend north-west of Kutki, but, to the south again, in the Kasor Range, they are found on the surface slopes continuously over a distance of more than 30 miles, and once more near the foot of the southern steep face of the independent mass of Sheik Budin. In this locality there are also thick Upper Jurassic limestones higher up the slopes. The great plateau of the Potwar lies behind the Salt Range: on its northern edge and in the adjoining foot-hills of the Himalayas, limestones build prominent hilly outcrops. They include Upper Jurassic limestones in the Kala Chitta Range and neighbouring hills, together with great inliers of Nummulitic limestone which crop up through the surrounding Siwalik strata and the alluvium; in quality they resemble those of the more southern areas already described. Details of their distribution are available in papers by D. N. Wadia and G. de P. Cotter. At Wah, a station between Taxila and Hassan Abdal, 27 miles north-west of Rawalpindi, Eocene limestones have been quarried by the Punjab Portland Cement Co. Ltd since 1923. These notes are based on accounts given by E. R. Gee.

The high-grade Nummulitic limestones just mentioned continue westwards from the Potwar into the Kohat district of the North-West Frontier Province, where they are extensively developed, and in the tribal territory to the north of Kohat, Jurassic limestones are known to occupy wide areas. Some account of the marble occurrences of this Province have been given on another page, and although it has been described as 'exceedingly rich in deposits of limestone of varying degrees of purity', they have not as yet been investigated and described in detail. Limestone is burnt for lime at Nowshera, Ghundai Tarako, Maneri, Kohat and other places. A. L. Coulson has published analyses of Jurassic limestones collected in the Bannu district, in Waziristan and in the Shirani country of the Dera Ismail Khan district; of the Danian Dungan Limestone which 'caps the bare hog-backed hills east of the Harnai route to Quetta', further west in Baluchistan, and of the limestones of unknown age associated with the Janjal Plant Beds, also in Waziristan. Many of these are of first-class quality, but beyond Coulson's statement that 'they may be regarded as being typical of the limestone generally available in inexhaustible quantities in the North-West Frontier Province', little is known about them.

In eastern Baluchistan the greater part of Sarawan, Jhalawan and Las Bela is covered by a vast series of sedimentary rocks ranging in age from Carboniferous to Pliocene, a considerable proportion of which consists of limestones of the Oligocene (Nari), Eocene (Khirthar) and especially of the Jurassic period. The latter include a thickness of several thousands of feet of dark grey, extremely thick bedded, middle Jurassic stones, and of older, less massive, distinctly

bedded, darker grey limestone of Liassic age. They are the leading features of the orography, as huge, anticlinal bulges from which the overlying strata have been denuded away, so that there are usually rings of less lofty ridges surrounding them, built up in their turn by compact, hard, regularly bedded limestones, of much smaller aggregate thickness and of Lower Cretaceous age. They are clear white or red in colour and contrast curiously with the dark tinge of the great limestone masses which they encircle. The massive limestones found close to Quetta and in the region to the east of it, and which appear again in the Sulaiman Range and in the Zhob valley, are probably also of Lower Cretaceous age. The Jurassic limestones build up two principal groups of hills—the first occupies nearly the whole width of Sarawan, from the neighbourhood of the Quetta region, southwards and south-westwards until it is concealed by overlying deposits to the south-west of Kalat; the second occupies nearly the whole breadth of Jhalawan from east to west about Zari and Bhagwana. Here it divides into two principal branches, one of which strikes south-west through Nal and Jebri for some 60 miles or so before disappearing below Tertiary rocks towards Wasar, the other striking to the south towards Khozdar and Wad and continuing east of the Porali river and the Las Bela plain, almost to the sea coast, a distance of over 190 miles. Extending diagonally from north-east to south-west across southern Sarawan and northern Jhalawan, and wedged in, as it were, between their anticlinal limestone bulges already mentioned, is a lofty plateau of limestones of yet another age. It consists of Eocene rocks in the shape of an elevated synclinal trough surrounded by a slightly raised rim. Its edges are tall craggy limestone cliffs, with an underscarp of shaly beds. 'The massive limestone forming this immense plateau', writes E. W. Vredenburg, 'is a nummulitic limestone of white or pale-buff, or pale-grey colour, belonging to the Series described in the publications of the Geological Survey of India as Upper Khirthar or as Spintangi.' To the east and north-east of this great plateau the same limestone forms other scarped ridges striking a few degrees east of north; in the latter direction it is still 1,000 feet thick in the Bolan Pass, south-east of Quetta, beyond which it is to be found again in the mountain arc which curves to the south-east through the Marri and Bughti country, but, on the eastern flank of the arc, to the north of the Sham plain and thence to the Sulaiman Range, it is only represented by a few bands not more than 20 or 30 feet thick. The ridges on the east of the plateau continue to the south and into the Khirthar Range, which, rising to heights of over 6,000 feet, forms much of the boundary between Baluchistan and western Sind. It is composed of vast thicknesses of Nummulitic limestone, 'further reinforced by an enormous mass of overlying limestones, white or brown in colour, of Oligocene age, constituting part of the Nari Series of Indian geological nomenclature'. Again, throughout the whole length

of this part of Baluchistan and forming the western margin of the calcareous region as a whole, from Gidar and Nal to the northern edge of the Las Bela plain, the ranges consist of very great thicknesses of these same massive Nari Limestones.

The greater part of Sind is an alluvial plain deposited by the waters of the Indus, and its limestone resources are to be found in the ranges which lie to the west of the river. The Nummulitic limestone forms the crest of the Khirthar Range which bounds the plain of Upper Sind on the west, for a distance of approximately 112 miles as far as the latitude of Sehwan, and then continues to the south-east for a further distance of 70 odd miles. In the south-

ANALYSES OF LIMESTONES FROM PAKISTAN

DISTRICT OR AREA	LOCALITY	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Loss	REMARKS
Salt Range	Basharat	2.47	0.90		51.97	1.88	42.74	{ Sakesar stone. Eocene. Salt Range
"	Dandot	1.94	0.28	0.21	53.34	0.96	42.48	{ Sakesar stone. Eocene. Bird & Co.
"	Mari Indus	0.30	0.16	0.20	55.25	0.42	42.88	{ Khairabad stone. Eocene. Bird & Co.
"	Khairabad	1.52	1.55		53.10	0.33	42.57	{ Up. Jurassic stone
"	near Nali	1.98	0.78		53.88	0.22	42.70	{ M. Productus stone
"	near Chhidru	0.22	0.66		55.00	0.76	43.80	{ M. Productus stone
Trans-Indus Salt Range	Makarwal	3.45	1.85		51.46	1.06	42.41	{ Nummulitic stone
"	Malla Khel	2.56	1.46		52.91	0.54	41.64	{ Up. Jurassic stone
"	Sheik Budin	1.17	1.53		53.41	0.72	42.20	{ Up. Jurassic stone
Dehra Ismail Khan	Mughal Kot	3.52	1.57		51.45	0.64	41.16	Dunghan stone
Swat	Buner	0.74	0.50		53.32	1.74	42.86	{ Recrystallized limestone
Waziristan North	Isha Fort W.	1.20	0.52		55.02	0.06	43.27	
Waziristan South	Spli Toi	3.16	2.54		53.41	0.34	39.83	
Sukkur	Rohri	2.10	0.70	0.50	53.10	1.40	42.90	{ Nummulitic stone. A.C.G. Ltd

The Salt Range and trans-Indus Salt Range localities are in Jhelum and Mianwali districts of the West Punjab.

Dehra Ismail Khan, Swat and Waziristan are districts of the North-West Frontier Province.

Sukkur is a district of North Sind.

western portion of Lower Sind there are several sub-parallel ranges of hills with broad undulating plains between them; of simple geological structure they are, as a rule, asymmetrical anticlines in the centres of which the Nummulitic limestones have been exposed by denudation, and so it comes to be found building the higher parts of the Lakhi Range, which commences near Sehwan and extends southwards for about 80 miles; in the Bhit Range, south-west of the Manchar Lake, and in several smaller ridges, including one extending for some 20 miles, south of the Baran river. This limestone varies in thickness from a few hundred feet in Lower Sind, to about 1,000 or 1,200 feet at the Gaj river and probably to 2,000 or even 3,000 feet farther north. It is a pale white or grey, or, less frequently, a dark grey stone varying much in texture, from a hard, close, homogeneous material breaking with a conchoidal fracture to a soft, coarse and open variety. In places these rocks are underlain by members of the Ranikot Series, while above them usually come the Nari and the Gaj Beds, the whole sequence varying in age from the Eocene to the Miocene and each member of it being in some part or other a repository of limestones of economic importance. Thus, towards the top of the Ranikot Series there are often extensive limestone bands, while in some localities the Lower Nari Beds consist almost entirely of brown limestones, some hundreds of feet thick; resting upon the Nari Beds throughout Sind are the Gaj Beds—nearly 1,500 feet thick in their type section in the Gaj valley, and sometimes entirely made up of limestones. A very large area of such beds occurs to the north and north-east of Karachi, consisting for the most part of horizontal or low dipping, pale coloured limestones. It is hardly necessary to add that supplies of lime are abundant throughout Sind almost wherever rocks occur. Near Rohri on the Indus in Upper Sind, there is an exceptional occurrence, for a range of low hills rises from the surrounding alluvium and extends for over 40 miles to the south into Khairpur. It is mainly composed of Nummulitic limestone and is the source of the raw material for the Sind cement works.

LIMESTONES OF BURMA

Crystalline limestones of Archaean age are abundant in the frontier districts of Putao, Myitkyina and Bhamo, and in the Jade Mines Tract of Myitkyina there are many exposures of metamorphosed Cretaceous limestones, examples of which are burnt for lime at Kamaing. Limestones of this age also occur in the first defile of the Irrawaddy between Namti and Htonbo, but they are of greater extent in the second defile of the river where they form the narrows at either end, as well as the high cliffs about its middle. Proceeding farther south, crystalline limestones are common in the Ruby Mines subdivision of Katha district, while *kankar* is spread over a wide area on the surface of Irrawaddian rocks in the Mu

valley of Shwebo, where it used to be collected for ballast and semi-pucka road metal at Thanbo, Magyidon, Halin and Thayaing. Among the vast spreads of dolomite in the Shan States there are occasional exposures of high-grade Permo-Carboniferous limestones—dark blue, grey or black rocks which break with a conchoidal fracture, often forming outlying masses or capping ridges and knolls, with their precipitous walls rising high above the general level of the plateau around. Argillaceous limestones of Ordovician and Silurian types have also been mapped in this region. Bands of homogeneous, very compact, fine-grained limestone, of no great thickness, but often individually persistent for miles, occur amongst the Jurassic sandstones of the Northern Shan States and have been quarried by the Burma Corporation for use as fluxes in lead-smelting operations at Nam Tu. The Plateau Limestones of the Northern States descend to the level of the Irrawaddy plains to the north-east and east of Mandalay, and continue southwards into Kyaukse district where they have been metamorphosed by granitic intrusions into banded grey and white marbles, extensively quarried in bygone times. Mandalay Hill itself is mainly composed of crystalline limestones which were worked by the Public Works Department of the British administration, while the Sagyin Hills of the Sagaing district, on the right bank of the Irrawaddy, opposite Mandalay, are to a great extent built up of marble, used both as a source of statuary material and of lime. Lime is also made from Plateau Limestone at Tonbo, near the foot of the Shan Hills, and at Zebingyi, on the steep ascent to the plateau from limestones of Silurian and Carboniferous ages. At the base of the Shan scarps in the Yamethin district, crystalline limestones are quarried and burnt near Shanzu, for use locally as whitewash for pagodas but mainly for the sugar factory at Zeyawadi, near Toungoo. To the south and south-east of the Yamethin and Toungoo districts there are wide expanses of Plateau Limestone both in the Southern Shan States and in Karenni. Nummulitic limestones in 'considerable beds' are reported from the hills to the east of the Myittha river, between Kyaukpyauk and Indin in the Upper Chindwin district. Nevertheless, limestones of economic importance are of rare occurrence in the Tertiary rocks of central Burma, though at Maukthayet, in the Lower Chindwin district, lenticular deposits in Pegu clays are extracted and burnt on the spot. This product formerly found a ready market over a wide region in Upper Burma. Disconnected exposures of limestone, intercalated with shales and sandstones of Eocene age, are to be seen in the western parts of the Minbu and Thayetmyo districts among the foot-hills of the eastern flank of the Arakan Yoma. In Lime Hill, near Thayetmyo itself, there are Oligocene Limestones which are burnt for lime and also supply the raw material for Burma's only cement works.

In the Arakan division isolated occurrences of limestone, presumably of Tertiary age, occur here and there close to the coast

of the Sandoway district, from Taungup southwards to Gwa. Further south still, at Baumi, on a tidal creek of the Bassein coast, there is an occurrence described by W. Theobald as of exhaustless quantity, excellent quality and easy access for large, coasting vessels. Again, to the south of the Thamandewah creek, still in the Bassein district, Nummulitic limestones crop out for a distance of about 2 miles; regarding them W. T. Blanford wrote: 'The quantity is inexhaustible, the quality good and the access (by water) easy.' Limestones of similar quality are plentiful in Ramree Island off the coast of Kyaukpyu. In Tenasserim, limestones, doubtless a continuation of those which occupy so much of the Southern Shan States and Karenni, are known to occur in the Papun district. The Amherst district is largely plain country, but traversing the plains, more or less from north to south, until they converge in the Mahlwe massif, where the Ye subdivision, the Tavoy district and the Kingdom of Thailand meet, are three continuous ranges of hills which separate the coastal tract from the Ataran valley, form the divide between it and the Haungthra, and build the Dawna range between the Haungthra and the Taungyin, a river which for much of its course is the boundary between Burma and Thailand. It is in the broad valleys between these ridges that the well-known Moulmein Limestones come to the surface, either as expanses of rock protruding a few feet out of the soil, or as the lofty and vertical-sided, castellated and pinnacled hills so distinctive of this Permo-Carboniferous formation. It is generally a creamy or blue-grey rock of massive structure, sometimes bedded and occasionally with interstratifications of calcareous shales. The well-known caves of the Moulmein neighbourhood are in this formation. To the east of the Dawna Range, in the Kawkareik subdivision of north-east Amherst, the Kamakala Limestone, of doubtful Triassic age, forms the cores of the main hill ranges, easily recognizable from afar by the rugged profiles to which it gives rise. It is a hard, greyish rock of a subcrystalline character, frequently containing networks of calcite veinlets. Rao Bahadur Setu Rama Rao, to whom we owe most of our knowledge of its geology, has described three zones of these Moulmein Limestones in the Mergui district. The first, only accessible from the sea, is exposed in widely separated and isolated islands of the Mergui Archipelago, stretching from High Rocks off Tavoy Island, through the Marble Isles and Turret Islands to St Matthew's Island. The caves on some of these islands are the homes of the swifts whose nests are a delicacy of Chinese cuisine and a source of revenue to the authorities. The second limestone zone traverses the eastern part of the district, starting as a range of precipitous hills, near the source of the Klong Thampra, a tributary of the Lenya river, and forming a limestone chain, the links of which cross the Great Tenasserim river and continue on its western side to the limestone ridges of Kyauktaung and Tharabwin, and thence northwards to a point west of Pawut. The third zone is

almost parallel to this, and its best-known exposures are near the confluence of the Belusekhan and Khuhtaokhan streams with the Tenasserim river.

ANALYSES OF LIMESTONES FROM BURMA

DISTRICT	LOCALITY	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Loss	REMARKS
Mandalay	Tonbo	0.39	0.79		55.65	0.07		{ Permo-Carbo-
Shan States	Hokun	0.35	0.35		53.76	2.02		niferous stone
" "	Nampating	0.91	0.43		55.27	0.44		ditto
Kyaukpyu	Ramree	3.60	0.70		52.86	0.23		ditto
Bassein	Baumi	2.80	0.80		53.98			Eocene stone
Mergui	Turret Isles	0.10	0.27		55.51	1.00	43.72	{ Permo-Carbo-
								niferous stone

CEMENT

Almost all the cementing materials employed in building construction and civil engineering are made by calcination of minerals composed wholly, or in great part, of the natural compounds of calcium. The varying compositions of these minerals and the treatment to which they are subjected determine the properties of their roasted products, and so give rise to their division into the three main groups of the limes, plasters and cements. They all possess cementing properties, but by common usage the word 'cement' is applied only to the last of the three groups. In the case of the first two groups, the power of hardening, or 'setting', depends upon the replacement of some constituent which has been expelled by heat, as in the cases of quicklime and plaster of Paris. In the third group, the setting is a result of chemical action between unstable compounds formed from the original minerals at high temperatures. The term 'hydraulic' means that the lime or cement to which it is applied has the power of becoming hard under water. Hydraulic limes made from argillaceous limestones have been defined under LIMESTONES; manufactured at one time on a large scale from such materials as septaria from the London Clay, or calcareous nodules from the shales of the Lias, they have been largely superseded by Portland cement, a stronger and more reliable product. The preparation and properties of such natural cements were certainly known centuries ago in southern India, where remains of masonry dams exist in which the cementing mortar has been much less worn by the combined solvent and frictional action of the water than the brickwork embedded in it. This is not surprising when it is remembered that the common carbonate of lime, the *kankar* or *gutin* of the Indian plains, contains as a rule sufficient argillaceous matter to endow lime made from it with hydraulic properties. The only modern cement works in

the India of today manufacturing a 'natural cement' uses *gutin* as its principal raw material. The ancient Romans prepared a hydraulic cement from volcanic tuff which occurs at Pozzuoli, near Naples, and the term 'pozzolana' is still used for mixtures of lime with finely pulverized tuffs, volcanic scoria and even blast-furnace slags, which form cementing materials without subsequent calcination. According to J. B. Auden, pozzolanic materials are likely to be substituted in the future for part of the cement now consumed in mass concrete work, such as that involved in the construction of large dams, as pozzolana-Portland cement mixtures produce a strong concrete with great saving in the amount of cement used. He adds that in south India it has long been the practice to add *surki*, or crushed brick, to cement, and it is probable that this may act as a pozzolana rather than merely as an inert constituent. Pozzolanas have been defined by F. M. Lea as 'siliceous materials which, though not cementitious in themselves, contain constituents which at ordinary temperatures will combine with lime in the presence of water to form compounds which have a low solubility and possess cementing properties'. In the United States one of the pozzolanic materials in common use is pumice, and it has been suggested that crushed ash beds in the Deccan Trap, crushed cherty limestones and various other possible sources of supply should be looked for in India.

By reduction of its content of uncombined lime, hydraulic cement passes into Portland cement, a material first made by Aspdin of Leeds in 1824, and so called from its resemblance in colour to the well-known Portland Stone. It was later made by burning suitable mixtures of chalk and estuarine muds from the Thames and Medway, and the first true Portland cement manufactured in India was made in Calcutta from chalk imported as ballast in sailing ships and mud from the Hoogly river. It is manufactured today from finely ground, intimate mixtures of limestone and clay, or shale, which have to be adjusted in precise proportions by strict analytical control to ensure constant uniformity of composition in the finished product. The mixed materials, in the form of slurry, are heated to incipient fusion in rotating furnaces—long steel cylinders, 8 or 10 feet in diameter, lined with refractory bricks and slightly inclined so that the mixture travels gradually down to the hottest end, the heat being supplied by burning gases from powdered coal. The calcined material then passes through a shorter, rotating, cooling cylinder where it yields its heat to the ingoing air for the combustion cylinder. The 'clinker', as the burnt product is termed, after cooling and mixing with such quantities of gypsum as will control its setting time, is reduced in ball and tube mills to the powdered form in which it is marketed. This must be fine enough for three-quarters of the finished product to pass a screen with 40,000 apertures to the square inch. The composition of a typical Portland cement slurry, before calcination, and of the

normal cement at present manufactured in India, as given by Auden, are as follows:

COMPOSITION OF TYPICAL INDIAN PORTLAND CEMENT SLURRY

SLURRY		RATIOS OF SLURRY	NORMAL PORTLAND CEMENT
SiO ₂	14.5%		21.3
Al ₂ O ₃	3.5		6.0
Fe ₂ O ₃	1.5	CaO to SiO ₂ + Al ₂ O ₃ & Fe ₂ O ₃ = 2.20	2.7
CaO	43.0	CaO to SiO ₂ = 2.97	63.2
MgO	1.5	SiO ₂ to Al ₂ O ₃ & Fe ₂ O ₃ = 2.90	2.9
SO ₃	..	Al ₂ O ₃ to Fe ₂ O ₃ = 2.34	1.8
Alk.	0.5		....
Ig. Loss	35.5		1.3
Insol. Res.	..		0.2

The exact constitution of the chemical compounds which make up Portland cement and the changes which they undergo on setting do not appear to be perfectly understood. Textbooks state that the essential constituents are thought to be a tricalcium silicate $3\text{CaO} \cdot \text{SiO}_2$ and a tricalcium aluminate $3\text{CaO} \cdot \text{Al}_2\text{O}_3$. On mixing the cement with water hydration of these anhydrous salts takes place, resulting in the formation of the hydrated calcium silicate $2\text{CaSiO}_3 \cdot 5\text{H}_2\text{O}$, hydrated tetracalcium aluminate $4\text{CaO} \cdot \text{Al}_2\text{O}_3 \cdot 12\text{H}_2\text{O}$ and slaked lime, compounds which crystallize out in masses of interlacing needles and so give cement its strength. Many special varieties of Portland cement are manufactured, each of which is adapted for use in some particular set of circumstances; of particular interest to India are the so-called 'low-heat' cements employed in the concrete work of large dams and now obtainable from works in the country.

Although cements of the Portland type had been made on a small scale about the environs of Calcutta from 1875 onwards, and at Madras from about 1904, where sea-shells were used as a source of carbonate of lime, and in all probability at other places as well, the Indian cement industry really commenced on a large scale in 1914, when the Indian Cement Co. started its operations at Porbandar in Saurashtra, utilizing the sub-Recent, aeolian, miliolite limestone, the well-known Porbandar Stone, with local clays reinforced by the addition of powdered granophyre from the Barda Hills. By 1923, in the first edition of this book, the establishment of factories at Katni, Madhya Pradesh, in 1915, and at Lakheri, in Bundi, Rajasthan, was noted; the second edition in 1936 was enabled to chronicle the further installations at Dwarka, Saurashtra (1922); Japla, Bihar (1922); Mehgaon, Madhya Pradesh (1922); Banmore, Gwalior (1923); Wah, Punjab (1923); Kymore, Madhya

Pradesh (1923); and Shahabad, Hyderabad (1925). The additions to the list since then are given in the table on pp. 352-6.

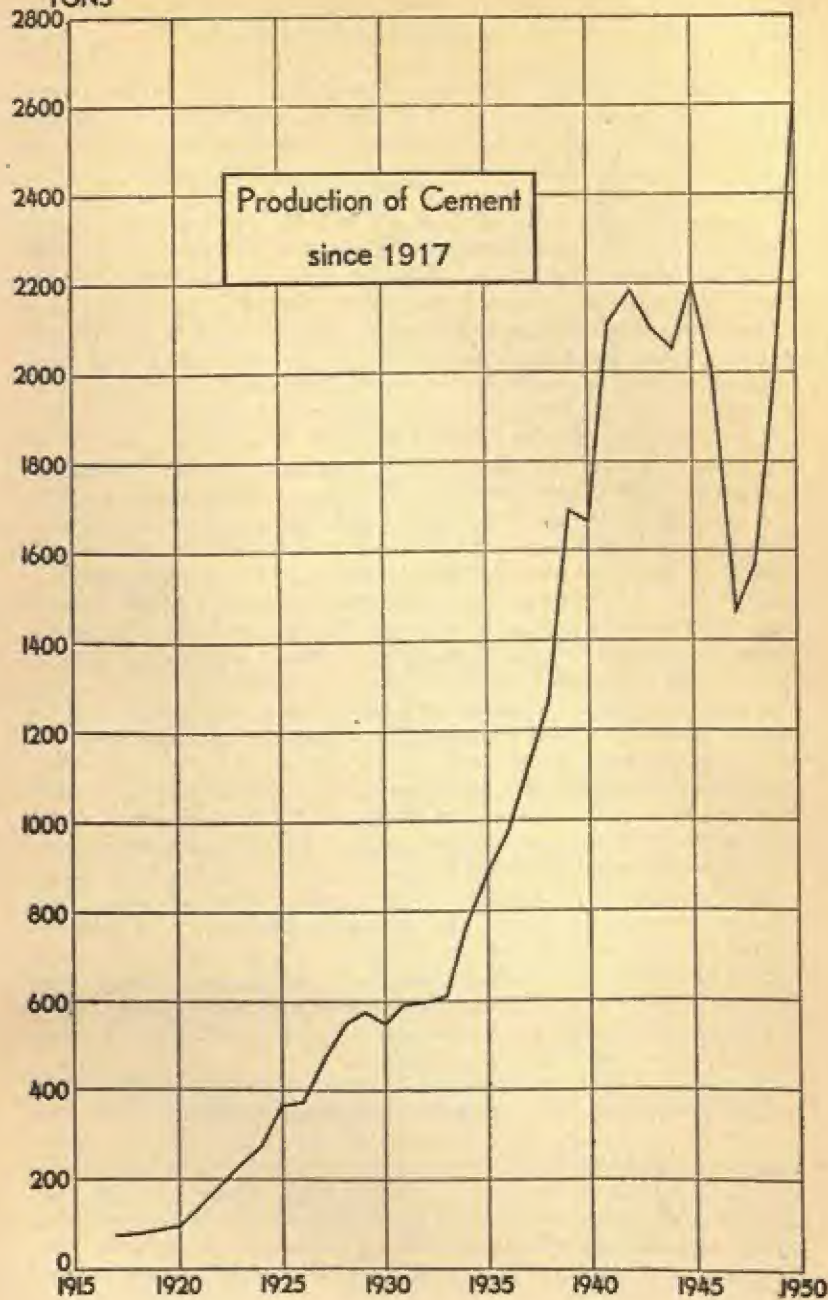
In 1920, the production of Indian cement was 91,253 tons and the imports 155,480 tons; by 1930 production had risen to 563,929 tons; the million-ton mark was passed in 1937 with an output of 1,197,188 tons, and by 1941, 2,110,623 tons were made. In 1949 the output was 1,997,392 tons, and as approximately 1.4 tons of limestone are consumed in making 1 ton of cement, besides the other materials, some 2.8 million tons of limestone were consumed in that year for this purpose alone. In the table below, the average annual production and import figures are given for the 27 years 1920 to 1946, from which it will be apparent that imports, which averaged about 139,000 tons per annum in 1920, have dwindled into insignificance as Indian output has grown. In 1946, the productive capacity for undivided India was of the order of 2.85 million tons per annum; by the end of 1950 this had increased to about 3 or 3.1 million tons. On the division of India in 1947, the cement works at Karachi, Rohri, Dandot, Wah and Sylhet passed under the jurisdiction of Pakistan.

AVERAGE ANNUAL PRODUCTION AND IMPORTS OF PORTLAND CEMENT, 1920-46

PERIOD	PRODUCTION	IMPORTS
	<i>tons</i>	<i>tons</i>
1920-3 ..	152,584	138,561
1924-8 ..	407,294	123,337
1929-33 ..	588,135	101,823
1934-8 ..	1,015,183	48,946 (includes 3,647 tons other varieties)
1939-43 ..	1,970,482	6,247 { " 2,795 " " " }
1944-6 ..	2,101,186	936 { " 266 " " " }

Outstanding events in the history of the Indian Portland cement industry are as follows: the imposition of a duty on imported cement by the Government of India in 1926, which amounted to Rs 9 per ton on Portland cement (excluding white Portland cement) and to Rs 15 per cent *ad valorem* on cement (excluding Portland cement other than white Portland cement); the establishment in 1927 of The Concrete Association of India for the purpose of giving free advice and assistance and for the publication of its periodical the *Indian Concrete Journal*; the formation in 1936 of the Associated Cement Companies Ltd, and the institution in the same year of the Dalmia Managing Agency which controls another group of factories in different parts of the country. For some time after this there was destructive competition between these two groups though eventually a compromise was reached. By 1946 the twelve factories working under the Associated Cement Co. Ltd had a

THOUSAND
TONS



combined production of 1,438,878 tons, or 74 per cent of the total production that year for undivided India of 2,040,201 tons.

Limestones suitable for cement manufacture are found in many of the geological formations of India and Pakistan but they are comparatively scarce in Burma; many of them have already been referred to under LIMESTONES, and their diversity of age can be seen from the following short list, which might be greatly extended. Dark grey, flaggy rocks of Lower Vindhyan age are utilized at Tikuri, Jabalpur district; stones of similar age at Kymore and Mehgaon in the Katni area of Madhya Pradesh; limestones, again from the Lower Vindhyan in the slopes of the Kymore Range, are mixed with shales from Daltonganj, at the Japla works in the Palamau district of Bihar; black Nummulitic limestones mixed with local alluvial clays serve as raw materials at Wah in the West Punjab; in Gwalior supplies are taken from outcrops close to the works belonging to the Gwalior System of Purana age; in the Krishna and Guntur districts of Andhra, from the Kurnool formation; at Rohri in Sind from the Eocene Nummulitic Group, and at Lakheri, Bundi, Rajasthan, from the Lower Bhander Group of the Upper Vindhyan. As many of the limestone deposits which possess a chemical composition suitable for cement manufacture and which lie in appropriate locations have already been leased, and as future developments may necessitate the siting of factories in less favourable situations, particularly those which may have to be erected in connexion with the construction of some of the major dams contemplated in India, and which may demand the use of one to two million tons of cement for their concrete requirements, the question of the beneficiation of sub-standard limestones arises. This usually involves the adoption of a flotation process and the problem has been discussed at length by Auden, who has stated that amongst the limestones in northern India which merit such consideration are the Mandhali stones of Kalsi, Dehra Dun, Uttar Pradesh, which are alternations of natural cement rock with more siliceous types; the crystalline metamorphic stones of Bhainse Dobhan in Nepal, which have rather abnormally high silica and alkali contents; the similar stones of Chhanggu in south-east Sikkim; the crystalline limestones of Gangpur and, finally, some of the more siliceous and magnesian stones of the Rohtas Stage in the Mirzapur district of Uttar Pradesh.

Both the Indian and Pakistanian cement industries are closely integrated with the economic and industrial structures of the two countries, and as these structures grow the respective cement consumptions will expand. On the assumption that 0.63 ton of cement would be used for 100 cubic feet of concrete, without the help of pozzolanas or air entrainment, Auden has estimated that 10.39 million tons of cement will be required for certain major Central and Provincial dam projects in India alone; further vast

quantities will be called for when the modernization of some of the 270,000 miles of road in undivided India comes to be undertaken, and the suggested national highways of India, which are to link the major ports with each other and with Delhi, are laid down. Apart from the utilization of cement and concrete in heavy constructional work—dams, reservoirs, retaining walls, roads, bridges, factories, warehouses, wharfs, jetties and the like, there are growing calls for such materials for the ornamental details of buildings, frames and mouldings, for pipes and blocks, posts and beams, and for all the diverse purposes for which artificial stone can be applied.

The works of the Burma Cement Co. Ltd are situated on the west bank of the Irrawaddy near Thayetmyo; started in February 1937 they have a capacity of 60,000 tons per annum and are the only ones of their kind in the country. The raw materials, limestone and marl, are won from quarries on Tondaung Hill, three miles from the works and 750 feet above them, transported down the hill by ropeway to be dumped into a storage bunker, from which they are loaded into metre-gauge railway wagons by gravity and conveyed to the crushing plant. Thence they are fed to the raw mill and ground with water into a slurry, containing about 40 per cent of moisture, which is elevated to four slurry storage tanks and conditioned by air agitation. A slurry scoop feeds the material into the chimney end of the kiln—a cylindrical furnace, lined throughout with refractory bricks, 251 feet long and rotating at 50-55 seconds per revolution. The kiln is fired by natural gas from the gas-field at Pyaye, already described under NATURAL GAS, which is supplied through a 6-inch pipeline, eight miles in length. After processing in the kiln, the slurry comes out from the burning end as clinker, which is later fed by gravity into the cement mill and ground to the grade required. It is then air-blown for a distance of 500 yards through a 4-inch pipe to four cement silos situated on the river front. From the silos the cement is elevated to the top of the packer building, where it is discharged into a rotary sieve and thence into a hopper, via a pneumatic extractor to the packer, where it is filled into paper sacks at the rate of 960 sacks per hour and carried by conveyor to the flats at the river bank. The whole of the works are electrified and the water requirements of about 250,000 gallons per day are obtained from two tube-wells. The works were evacuated from 1942 until 1946 and the plant was denied to the Japanese. After rehabilitation had taken place and production had been started once again, insurgents against the Government of Burma took possession. Towards the end of 1950, the Company was again enabled to return and hoped to be making cement once more by July 1951. Work actually commenced again in September 1951 and in the following two years a total of 77,500 tons of cement was produced, the whole of which was sold within Burma.

CEMENT WORKS IN INDIA

Name of Company	Site of Works and Date of Commencement	Capacity of Plant in Tons per annum	Kind of Cement made	Source of Limestone	Distance of Limestone from Works	Analysis of Limestone			Source of Gypsum	Source of Laterite or Bauxite	Amounts of Raw Materials in Tons for one Ton of Cement
						SiO ₂ %	CaO %	MgO %			
Associated Cement Companies Ltd	Khalari Palamau, BIHAR (1936)	100,000	Ordinary Portland and Rapid hardening	Khalari Bhokbuka Churi Sarle Chaibasa	Within one mile radius 8-9 miles 167 miles	15.0	43.7		Badwasi in Jodhpur	Dhaura	1.55 limestone 0.019 laterite 0.05 gypsum
Ditto	Chaibasa Singhbhum, BIHAR (1947)	200,000	ditto	Rajnanka	About 2 miles	7.60 to 23.50	38.60 to 50.20		Jamsar in Bikaner	Dhaura	1.53 limestone 0.018 laterite 0.03 gypsum
Jhajha Cement Industries Ltd	Jhajha in Monghyr, BIHAR (1946)	30-40 per diem	Natural cement	Local <i>kankar</i> limestone from Lerua Pahad	..	17.90 to 3.41	37.46 to 51.37	1.54 (<i>kankar</i>) 2.03 (limestone)	..	8 miles N. E. of Jhajha	0.95 to 1.15 <i>kankar</i> 0.2-0.4 limestone 0.05 bauxite 0.03 gypsum
Kalyanpur Lime and Cement Works Ltd	Banjari in Shahabad BIHAR (1946)	36,000	Ordinary Portland	Banjari	Within mile	3.0 to 15.0	40.0 to 50.0	1.50 to 3.50	Bikaner	..	1.34 limestone 0.18 clay 0.05 gypsum
Rohas Industries Ltd	Dalmianagar in Shahabad, BIHAR (1946)	300,000	ditto	Dumarkhor Ramdihra Kauriari in Rohas Hills Banjari	50 miles 16 miles 30 miles 32 miles	CaCO ₃ 70 to 94% MgCO ₃ 1 to 4%			Bikaner	Katni	1.72

Sone Valley Portland Cement Co. Ltd	Palamau, BIHAR (1922)	220,000	Rohtas Portland & Rohtas Rohtacrete-Hills hardening	..	9' 44 46' 52	Jamsar in Bikaner, Kavas in Jodhpur, Rishikesh in U.P.	1' 67
Associated Cement Companies Ltd	Sevalia, BOMBAY (1951)	200,000	Ordinary Portland and Rapid hardening	13 miles	15' 4 45' 4 0' 7	Kavas & Kapadvanj Badwasi, 58 miles Rajasthan away	1' 42 limestone 0' 069 bauxite 0' 042 gypsum
Ditto	Shahabad, HYDERABAD (1925)	240,000	ditto	3 miles	9' 9 47' 9	Kavas in Jodhpur, Jamsar in Bikaner	1' 53 limestone 0' 055 clay 0' 04 gypsum
Andhra Cement Company Ltd	Vijayawada, (Bezawada), ANDHRA (1940)	100,000	Ordinary Portland	78 miles	10' 0 48' 0 1' 0	Pulicat Lake, Nellore	1' 5 limestone 0' 1 clay
Associated Cement Companies Ltd	Tadepalli in Guntur, ANDHRA (1940)	80,000	Ordinary Portland and Rapid hardening	25 miles 7 miles	11' 0 25' 3 to to 32' 0 48' 1	Ariyalur in Tiruchi- rapalli	1' 61 limestone 0' 006 clay 0' 04 gypsum
Ditto	Madukkarai in Coimbatore, MADRAS (1934)	280,000	ditto	1 1/2 miles 3 miles	12' 6 46' 7	ditto	1' 43 limestone 0' 11 clay 0' 0013 bauxite 0' 05 gypsum
Dalmia Cements Ltd	Dalmiapuram in Tiruchirappalli, MADRAS (1939)	220,000	Ordinary Portland	Within 3 miles	3' 0 44' 0 0' 6 to to 12' 0 52' 0 2' 0	Uttathur & Kunnam in Tiruchira- palli	1' 27 limestone 0' 27 clay 0' 04 gypsum

CEMENT WORKS IN INDIA

Name of Company	Site of Works and Date of Commencement	Capacity of Plant in Tons per annum	Kind of cement made	Source of Limestone	Distance of Limestone Works	Analysis of Limestone			Source of Gypsum	Source of Laterite or Bauxite	Amounts of Raw Materials in Tons for one Ton of Cement
						SiO ₂ %	CaO %	MgO %			
India Cements Ltd	Sankarnagar, Talaiyuthu, MADRAS (1949)	100,000	Ordinary Portland	Talaiyuthu	1½ miles	10.5	48.0		Ramanathapuram district	..	1.35 limestone 0.15 clay 0.045 gypsum
Associated Cement Companies Ltd	Banmore Gwalior, MADHYA BHARAT (1923)	60,000	Ordinary Portland and Rapid hardening	Kailaras Semai Ochan	34 miles 42 miles	10.0 to 16.0	42.6 to 47.6		Badwasi in Jodhpur	..	1.28 limestone 0.04 gypsum
Ditto	Kymore Jabalpur, MADHYA PRADESH (1923)	350,000	Ordinary Portland and Rapid hardening	Barapara Bara Khalawara Mehgaoon Katni	2 miles 14 miles 7 miles 28 miles	7.7	48.8		Badwasi in Jodhpur	Katni	1.54 limestone 0.08 clay 0.008 laterite 0.036 gypsum
Mysore Iron and Steel Works	Bhadrahati, MYSORE (1938)	80,000	Ordinary Portland	Bhadrigund	13 miles	4.0 to 7.0	50.0 to 52.0	1.0 to 3.0	Tiruchirappalli	..	1.3 limestone 0.04 gypsum 7 c. ft. sand & clay
Orissa Cement Ltd	Rajgangpur, ORISSA (1951)	150,000	..	Lanjiberna	8 miles	2 to 8	47.0 to 51.0	1.5 to 3.5	Bikaner	..	1.3 limestone 0.21 clay 0.03 laterite 0.04 gypsum

Associated Cement Companies Ltd	Surajpur Patiala, PEPSU (1939)	300,000	Ordinary Portland and Rapid hardening	Malla Hills	7 miles	6.2 51.2	Jamsar, Bikaner Badwasri, Jodhpur	1.43 limestone 0.16 clay 0.05 gypsum
Dalmia Dabri Cement Ltd	Dalmia Dabri, PEPSU (1939)	60,000	Ordinary Portland	Local Kankar	Within miles	5 10.0 43.0 13.0 45.0 2.0	Jamsar	1.5 limestone 0.07 clay 0.03 mafi 0.04 gypsum
Associated Cement Companies Ltd	Lakheri, RAJASTHAN (1916)	325,000	Ordinary Portland and Rapid hardening	Garrum- pura and from bet- ween Lakheri & Chaumali	Within miles	3 15.4 44.9	Jamsar Badwasri	1.55 limestone 0.006 laterite 0.05 gypsum
Ditto	Dwarka, SAURASH- TRA (1922)	180,000	Ordinary Portland and Rapid hardening	North and South of 3 miles Works	3 miles	2.8 51.6	Kutch & Mithapur	1.20 marlstone 0.47 clay 0.03 gypsum
Ditto	Porbandar, SAURASH- TRA (1914)	42,000	ditto	Aditania and Ranawao	11 miles	3.2 51.9	Kavas in Jodhpur & Mithapur	1.32 limestone 0.24 clay 0.20 sand 0.38 gypsum
Shree Digvijay Cement Co. Ltd	Sika Port, SAURASH- TRA (1949)	100,000	Ordinary Portland	Gop	35 miles	6.0 48.0	Rajasthan	1.4 limestone 0.3 clay 0.04 gypsum
Travancore Cements Ltd	Kottayam, TRAVAN- CORE (1949)	50,000	ditto	Shells from Vembanad Lake	12 to 20 miles	0.50 54.5	Tiruchira- palli & Ramana- thapuram	1.19 shells 0.28 clay 0.07 sand 0.03 gypsum

CEMENT WORKS IN PAKISTAN

Name of Company	Site of Works and Date of Commencement	Capacity of Plant in Tons per annum	Kind of Cement made	Source of Limestone	Distance of Limestone Works	Analysis of Limestone			Source of Gypsum	Source of Laterite or Bauxite	Amounts of Raw Materials in Tons for one Ton of Cement
						SiO ₂ %	CaO %	MgO %			
Assam-Bengal Cement Co.	Chhatak in Sylhet, E. PAKISTAN, (1932)	60,000	Ordinary Portland	Khasi Hills Assam	10.2 miles	1.83	53.46	0.80	Bikaner	..	1.27 limestone 0.22 clay
Associated Cement Companies Ltd	Wah, Attock, W. PUNJAB, (1923)	173,000	Ordinary Portland and Rapid hardening	Wah and Hassan Abdal Hills	Near Works	0.40	55.7		Khewra, Dandot	..	..
Dalmia Cement Ltd	Dandot, W. PUNJAB (1940)	250 per diem	Ordinary Portland	Near Works	..	..			Salt Range	..	1.28 limestone 0.32 clay 0.05 gypsum
Associated Cement Companies Ltd	Rohri, SIND (1938)	90,000	Ordinary Portland and Rapid hardening	Rohri, Jagir Hills	Within mile	2.0	53.6		Spintangi	..	..
Dalmia Cement Ltd	Shantinagore, Drigh Road, Karachi, SIND (1938)	750 per diem	Ordinary Portland	Bislatar Hills	..	6.05 to 14.98	43.12 to 50.14		Jungha & Metung	..	1.6 limestone

GYPSUM

Gypsum, the hydrated sulphate of calcium, $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$, is a widely distributed mineral often abundant in thick beds in sedimentary formations and frequently associated with rock salt. Its clear crystalline variety is known as selenite; its pure, massive, granular modification as alabaster; its fibrous kind is termed satin spar, while the natural calcium sulphate without any water of crystallization is the mineral anhydrite.

Ground gypsum is an excellent top dressing for some types of agricultural land. A. B. Wynne, the geologist, noted in 1875 that the wheat-fields of Kohat gave better yields on the soils of the gypseous clays than elsewhere, though he added that the advantages to be derived from its use were apparently unknown and the mineral was then entirely neglected. Its usefulness in small quantities to the growth of the monsoon crops of south Bihar was demonstrated over 25 years ago, for in addition to supplying calcium to the soil for those plants which need this element, it has the power to 'fix' ammonia and so prevent the loss of organic nitrogenous compounds. It is indeed a constituent of several compound fertilizers. This power of fixing nitrogen is taken advantage of in the manufacture of ammonium sulphate from synthetic ammonia, by passing the gaseous ammonia through a suspension of gypsum or anhydrite in water, through which a stream of carbon dioxide is also passing at the same time. It is the basis of the process adopted at the Sindri fertilizer works, the ammonium sulphate being recovered from the solution, while the calcium carbonate, in a form eminently suitable for cement manufacture, is precipitated. Very large tonnages of gypsum will be required for this purpose alone.

Hitherto, the most important outlet for the mineral in India and Pakistan has been to the cement industry, in which it is employed as a retarding agent to control the setting time of the finished product. The quantities involved are dealt with in a later paragraph.

Clear rock gypsum, or alabaster, is still employed for ornamental and artistic work, carvings, statuary and the like. Vases and similar ornaments fashioned from blue-grey and pink gypsum are sold at Dalwad and other places in the West Punjab. Clean, ground gypsum is known as 'Mineral White' or 'Terra Alba', and finds its applications as a filler in the paint, rubber and cotton trades; in fertilizers; in insecticides for the control of weevil in grain stores; as an underground dusting agent in coal mines; as a heat insulator; and in the preparation of plasters and blocks for acoustical and general building purposes.

When gypsum is heated to about 120°C . it loses some, though not the whole, of its water of crystallization, leaving behind a white substance, the well-known plaster of Paris. This material when wetted forms a soft plastic mass which becomes hard in the course

of a few minutes. As it expands slightly during setting it can take a sharp impression of any mould into which it is forced. Eastern peoples have made use of this property for centuries: the whole of the stucco work of the ancient cities of Khotan consists mainly of plaster of Paris, its figures and images moulded by a process of appliqué. In Sind, the lattices and open-work screens of houses have been cast in it from early times. It is the foundation alike of the stained glass windows of the Marwaris and of the *shish* mosaics of Rajasthan and the Punjab. Plaster of Paris, so invaluable for taking casts, modelling and making moulds, has manifold uses ranging from the surgical wards of hospitals to the workshops of potteries, where it gives shape to cups, jugs, plates, basins and other wares. In the building trade it forms the finishing surface for interior walls and is the basis of many proprietary plasters and cements, fire-proofing materials and a variety of 'plaster boards' used for walls, partitions, ceilings, etc. Common salt mixed with plaster of Paris accelerates its rate of setting while other substances, including borax and alum, have a retarding action. Keene's cement, widely employed to repair cracks in plaster work, is mainly a mixture of plaster of Paris and alum, which sets much slower and becomes somewhat harder than the pure material. If gypsum or plaster of Paris is heated above 200°C . the whole of the water of crystallization is driven off, the power of setting is lost and 'dead-burnt' plaster, corresponding to the mineral anhydrite, CaSO_4 , is formed. Both gypsum and anhydrite are extremely important minerals in Indian industrial life from yet another aspect, for if future geological investigations do not reveal larger deposits of sulphur, pyrites or sulphide ores of the base metals than those at present known, it may well be that the country will have to turn to these two natural sulphates for the foundations of large-scale manufacture of sulphuric acid, as indeed other countries, including the United Kingdom, have lately been compelled to do. The question is discussed more fully under SULPHUR, and here it is only necessary to mention that anhydrite contains 58.8 per cent and gypsum 46.6 per cent of the sulphur trioxide radical SO_3 .

The table on the next page shows the growth of the gypsum industry in India.

Of the 610,300 tons raised during the decade ending 1943, approximately 52.5 per cent came from Rajasthan, 30 per cent from the Punjab, 14 per cent from Madras, 3 per cent from Sind and Baluchistan, and the remainder in small amounts from Garhwal, Kashmir and Rewa. A comparison of the production for the three years 1944-6 with that of the triennium 1947-9 is important because the former came from undivided India and the latter mainly from India without Pakistan. Of the total 262,917 tons won in the first period, 29.1 per cent came from the Punjab, 5.4 per cent from Baluchistan, 46.4 per cent from Rajasthan and 18.3 per cent from Madras; thus more than one-third of the gypsum was derived

PRODUCTION OF GYPSUM, 1914-50

PERIOD	AVERAGE ANNUAL PRODUCTION	VALUE
	Tons	Rs
1914-18 ..	18,857	14,625
1919-23 ..	35,133	45,407
1924-8 ..	40,399	93,937
1929-33 ..	49,447	96,322
1934-8 ..	52,478	1,14,483
1939-43 ..	69,782	2,24,867
1944-6 ..	87,639	4,12,720
1947-9 ..	89,820	7,94,172
1950 ..	206,366	13,76,917

The figures from 1947 onwards relate to the Indian Union only.

from deposits in the Jhelum (Salt Range) district of the Punjab and from Baluchistan, which later were to pass to Pakistan. Of the total 269,461 tons of the second period (1947-9), 60.8 per cent was raised in Rajasthan (made up of 37.9 per cent from Jodhpur, 22.7 per cent from Bikaner and 0.2 per cent from Jaisalmer), 32.5 per cent from Madras and 6.6 per cent from Saurashtra; in this way India soon made good the loss of some of the earlier sources of supply. The rapid growth of Indian production over these later years is very significant; starting with 48,669 tons, being her share of the combined total, in 1946, output rose to 50,569 tons in 1947; 78,948 tons in 1948; 139,944 tons in 1949 and to 206,366 tons in 1950. Over the four years 1947 to 1950, inclusive, 56,691 tons of gypsum were won in Pakistan, derived as to 70.4 per cent from the West Punjab, 16.8 per cent from Sind and 12.8 per cent from Baluchistan.

Beds of gypsum of some thickness occur at several places in and about the Great Indian Desert, especially in sunken areas surrounded by low hills and once occupied by salt lakes. In Jodhpur, a bed five feet thick occupies an area of about 8 square miles at Badwasi, eight miles north-north-west of Nagaur, and lies immediately below the surface. Similar occurrences are found at Madpura near Kavas and at a number of other localities. The Badwasi deposit is worked by the Associated Cement Co. Ltd, and of the 54,338 tons raised in 1950 some 43,470 tons were consumed in the cement works at Kymore, Lakheri, Kalari, Banmore and Surajpur while the remainder was supplied to the country. The reserves of gypsum available at some deposits in Jodhpur are as follows:

RESERVES OF GYPSUM AT SOME DEPOSITS IN JODHPUR

Locality	Tons	Locality	Tons
Badwasi ..	800,000	Phalsund ..	972,000
Kavas ..	2,061,000	Utarlai ..	7,499,000
Pilanwasi ..	1,040,000	Khutani ..	1,373,000
Dakoria ..	1,271,000	Dhirera ..	936,000
Manglod ..	8,000,000	Bhadaua ..	500,000

TOTAL .. 24,452,000 tons

Borings near Badwasi and Nagaur are said to have found further gypsum beds at depths of 296 and 66 feet, respectively.

The largest deposit in Bikaner is at Jamsar, a few miles from Bikaner City, where the mineral occurs in a bed four feet thick, under about three feet of overburden. The reserves at this and some other localities in Bikaner are as follows:

RESERVES OF GYPSUM AT SOME LOCALITIES IN BIKANER

Locality	Tons	Locality	Tons
Jamsar.. ..	25,000,000	Harkasar ..	118,000
Kaoni	1,000,000	Pugal (11-13 miles NW.)	1,299,000
Bharu.. ..	473,000	Siasar	351,000
TOTAL ..		28,241,000 tons	

The Jamsar deposit is exploited by Bikaner Gypsum Ltd, and in 1950 it yielded 116,834 tons, by far the greater part of which was dispatched to the Fertilizer Factory at Sindri. In the remaining producing region of Rajasthan, that is in Jaisalmer, the reserves are considerably less and have been computed at 1,341,000 tons, all of which are in the north-western division. Thus the total amount of gypsum available in Rajasthan, in so far as it has been assessed up to the moment of writing, may be taken as approximately 54 million tons.

Madras gypsum comes mainly from the Tiruchirapalli district, where it occurs in thin, irregular veins in the clays and limestones of the Utatur and Trichinopoly Stages of the Cretaceous System, distributed over an area of about 22½ square miles from Tappay and Periyakurukka in the south, to Chittale and Azur in the north. The individual veins are seldom more than 10 to 15 feet in length and up to 5 inches in width, but they usually lie close together. On the assumption that they extend to a depth of 50 feet, and there is no particular geological reason to limit them to this depth, over 15 million tons of gypsum are available here. The largest producers are the Trichinopoly Mining Works Ltd, operating in the Lalgudi and Perambalur taluks, from which 16,838 tons were taken in 1950 for the Associated Cement Companies' factories at Tadepalli and Madhukkarai and for the ammonium sulphate works of Fertilizers and Chemicals (Travancore) Ltd, at Alwaye.

It has long been known that gypsum is a characteristic mineral of shales and limestones of Jurassic, Cretaceous and Tertiary ages in Saurashtra, Kutch and Sind. The largest occurrence known in Saurashtra is at Ran, in Nawanagar, where D. R. S. Mehta estimated reserves of about 4 million tons. The gross reserves of Kutch are believed to be approximately 2 million tons, the richest deposit

being in sub-Nummulitic rocks near Umarsar. Gypsum of sub-Recent origin is also found in the alluvium of the creeks of Kutch and is worked there on behalf of cement manufacturers: again, at Kuda, in Dhrangadhra, it is present in clays, 12 to 14 feet below the surface, and in Porbandar, near Miani, it exists in yellow clay beneath a thin covering of mud. Examples of this type could be multiplied, but individually they have no great economic significance. They recall the segregated selenite crystals of the marine silts of the northern end of the Pulicat Lake in Nellore; the selenite scales of the black soils of northern Tirunelveli (Tinnevely) and of the Palladam taluk of Coimbatore, of near Kilakkarai of Ramana-thapuram, of the marine and estuarine silts of the Guntur and Chingleput coasts and Port Blair in the Andaman Islands. The mineral also occurs in limited amounts in the older alluvium of the Hamirpur and Jhansi districts of Uttar Pradesh.

In the extra-peninsular areas there are said to be large deposits in Kashmir lying along a tract of country, 15 miles in length, to the north of the Jhelum valley cart road, near Braripara in the Uri *tahsil*. In Spiti and Kanaur, beds of considerable extent and thickness have been described as resulting from the replacement of Carboniferous limestones through the action of hot, sulphurous, spring waters. Beds and lenses of gypsum have been found in rocks of Krol and related ages in Sirmur, Garhwal and Kumaun. Less than a quarter of a million tons are known in the Garhwal, Dehra Dun and Naini Tal districts of Uttar Pradesh. Thick beds of gypsum also occur in the Kangra Chu valley of Bhutan, though little is known of their extent. Such deposits as have so far been measured in Saurashtra, Kutch and Himachal Pradesh are capable of yielding about 7 million tons of gypsum.

In the Western Punjab of Pakistan, beds of gypsum with varying quantities of anhydrite crop out in the scarp slopes of the Saline Series of the Salt Range. They are particularly abundant in the Jhelum district and extend through Shahpur and Mianwali along the whole length of the southern flank of the Range, from Jalalpur in the east to Kalabagh on the Indus, and thence into the trans-Indus extensions of the same mountains. As a general rule, the more massive deposits underlie the Salt Marl Stage. The seams themselves, according to E. R. Gee, alternate with red, gypseous clays, contain mixtures of gypsum and anhydrite, and pass laterally into anhydrite with a little gypsum. In many cases practically no impurities are present; in other instances there are small admixtures of ferruginous clays. In the foot-hills of the area to the east of the exit of the Khewra gorge, 11 million tons are available; at Dandot, about three miles west of Khewra, there are 7 million tons of gypsum with anhydrite in the basal scarp slopes. Other important and relatively accessible deposits are to be found at Chanuwala (10 million tons) and at Makrach (9 million tons). At the western end of the Salt Range, near Daud Khel, reserves of easily workable,

high-grade gypsum with a proportion of anhydrite are estimated at 25 million tons. Further north, and still associated with the Salt Marl, there are some 5 million tons available in the Mari Hill south of the Indus. These and other localities between them possess, according to P. C. Das Hazra, a minimum total reserve of 71 million tons. The mineral is also known to occur in the Kala-bagh Hill to the north of the Indus river.

In the Baloch-Buzdar hills of Dera Ghazi Khan district, S. Tayab Ali states that beds of gypsum, 3 to 6 feet thick, in Eocene shales, continue north and south for miles along both banks of the Sarghar Lahar, but the locality is an isolated one.

Turning now to the North-West Frontier Province, there are immense deposits of probable Cambrian age in the Khasor Range, according to Dr E. R. Gee. Near Saiduwali, massive white and pink gypsum forms the major part of a 400-foot sequence of flaggy dolomite and shales of various kinds. 'The geographical position of these immense reserves,' adds Gee, 'to the west of the Indus and many miles from a railway, renders them of little economic value for the present.' But it is in the Kohat district that the greatest development of gypsum is to be found. Here, according to a recent publication of the Geological Survey of Pakistan, the beds lie in rocks of the Upper Eocene Nummulitic Series and are exposed in all the ridges extending from the vicinity of Bahadur Khel eastwards to the Indus, covering an area 50 miles long by 20 miles in maximum breadth. At Bahadur Khel itself, the known bands total about 100 feet, are of high quality and are well exposed around the salt quarries at Kharak and Jatta. Many million tons are said to be available by open-cast working. In the district as a whole, 'the quantity available is, from a commercial standpoint, unlimited', according to Dr Gee. In the Shirani country a band of gypsiferous shales, alternating with limestones, was traced by La Touche, from the Toi river in the south to the Zao defile in the north, a distance of 24 miles. In a measured section at Zor Shahr, 12 separate beds occurred, varying from 1 to $11\frac{1}{2}$ feet in thickness, and with an aggregate total of 50 feet.

In the Sibi district of Baluchistan, the gypsum deposits of Spintangi occur as two regular, sedimentary beds, 5 and $7\frac{1}{2}$ feet in thickness respectively, in Khirthar Limestones on the northern slopes of the Mian Zard Koh ridge, extending for 9 miles along the strike. Certain areas hereabouts are leased to and worked by the Associated Cement Companies Ltd. In the Anakoi *nala*, 7 miles from Chamalang in Loralai, S. Tayab Ali, in 1948, found 13 gypsum bands with a total thickness of 50 feet, and an exposure length of $1\frac{1}{2}$ miles: three million tons are probably available here down to a depth of 100 feet, but the locality is too remote for present development. Gypsum is also known to occur about the Ghaziaband Pass in the Quetta-Pishin district, and in the Kachhi district of Kalat, while certain surface and sub-surface deposits of the desert around

Nok Kundi in Chagai recall those of Rajasthan. Gypsum also occurs near Kotri in Sind, and supplies from this locality were used for some time in the cement industry. Gypsum of tolerable purity occurs abundantly, according to Blanford, in the upper parts of the Gaj (Miocene) Group in the Khirthar Range of Sind. Beds with thicknesses of 3 to 4 feet have been observed in the sections exposed in the Gaj river, and similar ones are frequently met with further northwards.

There are no gypsum deposits in Burma similar to those of the desert regions of Rajasthan or of western Baluchistan, and still less are there any typical evaporites such as those of the Salt Range and Kohat, which were derived originally from oceanic waters trapped in desiccating, land-locked lagoons and shallow arms of the sea. Selenite is common enough in the Pegu clays and shales of the Thayetmyo, Minbu, Magwe, Myingyan and Pakokku districts of central Burma, but only as thin laminae along bedding planes, or as narrow veinlets filling their cracks and joint planes. Its scattered condition prevents its profitable exploitation and no deposits have yet been found concentrated enough to be of economic interest.

Some idea of the magnitude of the reserves of the natural calcium sulphates can be gleaned from the figures already given for those deposits that have been investigated in both India and Pakistan and in all probability these will be considerably extended in the future. The production figures of the past furnish no guide to the output of coming years: it has been authoritatively stated that the Sindri fertilizer works alone will require some 2,000 tons of gypsum *per diem* when operating to full capacity. Judging from the consumption of 17 Indian cement works who have kindly furnished particulars, the whole cement industry working at capacity today (1950) consumes about 120,000 tons per annum and this is likely to increase rapidly. The annual output of gypsum and anhydrite in the world now exceeds ten million tons annually and is some measure of the importance of the mineral.

MARBLE AND OTHER ORNAMENTAL STONES

'Amongst the remains found on the Mohenjodaro site in the Larkhana district of Sind', wrote Sir Edwin Pascoe, 'were shaped and dressed blocks of polished marble, many of them evidently for building purposes. The stone resembles that from Makrana in Rajputana, whence we may imagine it to have been carried across the desert to the ancient city. Associated with these shaped blocks were found seals bearing a script having many resemblances to the Sumerian script of Mesopotamia. The marble quarries of North-Western India, therefore, appear to have an antiquity which it would be difficult to rival.'

The Makrana quarries are in Jodhpur and are believed to have supplied the stone for the Taj Mahal, erected by the Emperor Shah

Jahan (1628-58), at Agra as a mausoleum to the memory of his wife Mumtaz Mahal, a building which is regarded by most authorities as one of the most beautiful structures in the world. The Victoria Memorial in Calcutta is built of the same stone.

In many parts of Rajasthan there are marble occurrences of varying degrees of colour and grain in both the Delhi and Aravalli Systems. 'Almost everywhere in the extensive area occupied by its outcrops in North-Eastern Rajputana,' writes A. M. Heron, 'the Raialo Limestone—which passes up conformably into the lowest bed of the Alwar Series—affords good marble, quarried chiefly in the vicinities of Raialo in Jaipur, and of Jhiri in Alwar.' The stone is an excellent pure white, saccharoidal marble, though pink, pale grey and black kinds also occur. White marble from another band in the same rock sequence is quarried at Dadikar, in Alwar, while a handsome modification of the Kushalgarh Limestone forms a narrow-banded, black and white variety near Badgaon, close to the Alwar-Jaipur boundary. The Rajnagar Marble, again, a pure white stone, free from grey cloudiness, is exposed over wide tracts around Nathdwara, in Udaipur, and has given vast quantities of stone for embankments, palaces and temples, though these have made little impression on the reserves, which are for all practical purposes inexhaustible.

Marbles from Rajasthan, as well as suitable Vindhyan sandstones, were used for the preparation of filigree screens, which are such striking features in the internal decoration of many historic buildings. As an example, the marble work of the monument erected by Akbar over the remains of his friend Shaikh Salim, at Fatehpur Sikri, in 1581, may be mentioned. It is a pavilion of white marble, surrounded by a deep projecting dripstone of similar material, supported by marble shafts crowned by most fantastic brackets, shaped like the letter S. 'The outer screens', wrote H. G. Keene, 'are so minutely pierced that they actually look like lace at a little distance, and illuminate the mortuary chamber within with a solemn half-light which resembles nothing else that I have seen. The whole of this elaborate work, including the strange but most pleasing design of the brackets, appears to have been produced by the resident stone-cutters of the place, uneducated men earning probably an average wage of about a penny a day. I believe that no instance of such pure, patient workmanship, so dignified yet so various, is to be found in the world.'

'It is to be remembered', wrote Dr Heron in 1935, 'that the marbles of Rajputana, such as those quarried at Makrana, Rajnagar and Raialo, have important local uses as building stones for ordinary village houses, as well as their export as ornamental stone. A dilapidated village built of white marble and mud appears incongruous, but the available supply of marble is probably much in excess of any possible export, and there is always an abundance of inferior stone which cannot find an outside market.'

The North-West Frontier Province of Pakistan is well supplied with white statuary marble and has illimitable quantities of banded marbles suitable for building purposes. The white, saccharoidal stone of the Shahidmena and Kambela Khwar quarries, in the Mullagori country of the Khyber, is translucent in thin masses and equal in appearance to the best qualities from Makrana and from Carrara in Italy. After rough dressing at the Shahidmena quarries, it used to be taken into Peshawar by motor lorry, a distance of about 26 miles, where it was sawn into suitable sizes for ornamental building purposes. Marble of good quality also occurs at Maneri, in the Swabi *tahsil* of the Mardan district. Larger quantities still, of statuary grade, are available in the Ghundai Tarako ridge, on the boundary between the Swabi *tahsil* and the Buner tract of Swat. All these marbles were originally limestones, probably of Carboniferous age, which have been altered by intrusions of epidiorite. D. N. Wadia has described snow-white, massive marbles in bedded aggregates, up to 600 feet in thickness, in the Kunhar valley of Hazara, though the locality is not easily reached.

The Sagyin Hills, north of Mandalay in Upper Burma, are composed to a great extent of white marble, from which most of the images of Gautama, some of them of colossal size, which adorn the innumerable pagodas of the country, have been carved. Marble occurs also in the Kyaukse and Sagaing districts, while the great bands of the Ruby Mines region, in Katha, have their counterparts in the frontier ranges of the Bhamo, Myitkyina and Putao districts, between Burma and China.

Although the marbles of India are, in the words of V. Ball, 'probably unsurpassed for beauty by any to be obtained in any other part of the world', little use has been made of them with the exception of the cases mentioned. In the Coimbatore district of Madras there exist vast quantities of greyish-white and flesh-coloured stone, while the Chitaldrug and Mysore districts of Mysore contain further supplies of the former. Other deposits are known in the Salem, Madurai and Tirunelveli districts. The Archaean formations of Madhya Pradesh possess the 'Marble Rocks' in the Jabalpur district, and numerous excellent marbles have been found in the Betul, Chhindwara, Nagpur and Seoni districts. The beautifully marked, serpentinous varieties of the Sausar *tahsil* in the Chhindwara district deserve especial mention. Black and white marbles are said to be worked in the Mandi and Datla hills of Patiala, and a white stone was at one time quarried at the State Marble Works, some 8 miles from Narnaul railway station. According to F. Ahmad, fine-grained slightly dolomitic statuary marble occurs extensively at Ningha, about 16 miles south of Robertsganj in Mirzapur district of Uttar Pradesh.

Unusual varieties include the lovely green, pink and white, mottled rock from Harikua and its brecciated relative from Sandara in Baroda, Bombay; the black marbles of Rewa Kantha, Bombay;

the pale green, or dark green and yellowish, clouded marble of the Kurnool district, Andhra; the fine pale sea-green stones from the Narji formation of the Guntur and Krishna districts of Andhra, used in the sculptures which depict scenes from the life of Buddha and his previous births (*Jatakas*) at the Amaravati *stupa* and the Nagarjuna Konda *chaitiyas* datable from the second century B.C. to the third century A.D.; the onyx marbles of the Shahpur district, West Punjab; the green and yellow serpentinous marbles of the Mardan district, North-West Frontier Province, Pakistan, which A. L. Coulson describes as stones of considerable beauty capable of taking a good polish; the coralline varieties of the Lower Narbada valley, employed in building many ancient temples, mosques and palaces and remarkable for their thick bunches of branching bryozoa; the homogeneous yellow marble, and the yellow and grey, shelly kinds of Jaisalmer in Rajasthan, and, finally, the semi-sacred 'Abur Stone', a dark red, fossiliferous marble in which the organic remains have been changed into a yellow substance. This material is extensively used in northern India as a paving for the thresholds of temples, for fine carvings and inlay work, as in the mosaics of some of Shah Jahan's fine buildings; for memorial stones and tablets with incised inscriptions; for pierced grilles, brackets and tables, as well as for large building purposes.

The average annual production of marble over the decade ending 1938 was 5,823 tons, valued at Rs 1,54,973, and, with the exception of a small amount from the North-West Frontier Province of Pakistan, it came almost entirely from Rajasthan, where Jodhpur is the largest producer and is followed by Alwar and Jaisalmer. Marble quarrying in Rajasthan is a growing industry, the average annual output for the five years ending 1948 having risen to 16,929 tons, valued at Rs 3,50,888, and, in 1949 alone, to 26,616 tons of a value of Rs. 7,41,280.

The cost of transporting the marbles of Rajasthan by railway to the great cities, such as Bombay, Calcutta or Madras, has not only hampered the large-scale development of the quarries, but has favoured the trade in imported marble, chiefly from Italy and Greece. In normal pre-war times, the imports of 'stone and marble' had an average annual value of between Rs 7 and 8 lakhs.

India abounds in granites, granite-gneisses and related rocks which, suitably polished, would rival any of those produced for ornamental purposes in other countries, such as the Aberdeen granites of Scotland or the English Shap granite, but they remain undeveloped except for the more utilitarian purposes of road and railway making, and, more rarely, as roughly dressed constructional materials. J. A. Dunn mentions that some of the granite-gneisses of Chota Nagpur are beautifully figured and, being susceptible of a high polish, are suitable for wall panelling, stairways, architraves and lintels. The variety of such rocks amongst the crystalline formations is very great and includes the charnockites, first recog-

nized from a tombstone in a Calcutta churchyard, dating from 1695. Here should be included the syenites of the Mogok district of Upper Burma with their shimmering moonstone feldspars. In the Bellary district of Mysore alone, Bruce Foote, in 1895, listed 52 separate localities either where granite had been quarried, or where it still awaited trial. The supply of first-class stone, considering the district as a whole, he regarded as absolutely inexhaustible. Remarkable examples of workmanship in such granites are to be seen among the ruins of Vijayanagar, the capital of the Hindu Kingdom of the same name, 1339 to 1565 A.D., in the form of composite pillars, huge monoliths, large figures and a great stone trough over 41 feet in length. There are also pillars of polished porphyritic diorite in the remains of one or two of the temples. The granites of Dammur and Bailur, 11 miles due south of Bellary itself, are extraordinary rocks which have not yet been worked; of medium to rather coarse grain, they possess a deep rich red colour and would make superb decorative stones if well polished.

The banded haematite quartzites of the Archaean formations form another group of stones with good decorative possibilities. J. A. Dunn has described those of south Singhbhum with their thin, alternating layers of dark red, pale red and white colours delicately contorted into fine folds, as extremely hard and highly polishable stones which could provide materials of unusually striking appearance. In much the same category come the ribboned jasper rocks of the Sandur Hills and elsewhere. Bruce Foote described cliffs, three or four hundred feet in height, 2 miles north-west by north of Timappaghar, in Sandur, Bellary, as formed of banded jasper-haematite of vivid red and purplish grey tints, or greyish brown in stripes and often exquisitely vandyked, adding that it was one of the most richly coloured rocks he had ever seen and even in the rough state a material of great beauty. 'The jointing is most rectangular and kindly', he added, 'and well shaped blocks of sizes varying from a foot cube to several cubic yards in bulk, could easily be quarried.'

The dyke stones of southern India are often of attractive and pleasing appearance. A porphyrite of Tornagal Hill, in Hospet, Bellary, has a blackish-grey groundmass, full of large, bright, flesh-coloured feldspars; another at Hurlihal, in the Kudligi taluk of the same district, has rich green feldspars showing out of a blackish green matrix in large numbers; many of the lighter greenish diorites of this and adjoining districts are also unusually handsome stones. A remarkable reddish-brown feldspathic porphyry occurs on Kari-gutta Hill, overlooking Seringapatam in Mysore, and could furnish large supplies of stone fit for panels, vases, *tazzas* and similar articles.

Some of the serpentines commonly associated with the ultra-basic rocks of India, Pakistan and Burma, would doubtless prove suitable for ornamental purposes, if a demand should ever arise for stones of the class to which they belong; as yet, however, no attempt has been made to develop them. The potstones and steatites have

also been used in the construction of both temples and palaces, though, as their first name indicates, they are more widely carved into bowls, basins, plates and the like, for various culinary and domestic purposes. Many of the temples of Orissa, Mysore and some parts of Madras, contain examples of sculptured steatite, which, in general, have resisted weather action extremely well. Of finer varieties, only three can be mentioned here—the black, talcose rock, studded with crystals of magnetite, forming the polished pillars of Hyder's mausoleum at Seringapatam; the dark stone with a metallic lustre, occurring at Jambal Ghat, in the Chanda district of Madhya Pradesh, which the Mahratta authorities reserved for the manufacture of images, and the bluish grey soapstone from a mine in Jaipur, Rajasthan, used in Agra for the carving of delicate ornaments.

In any list of scarcer ornamental stones the following examples would certainly find a place amongst many others: the tinted, yellow-green epidotes of south Ranchi, Bihar; the unakites of Singbhum, with their large pink orthoclase and yellowish green epidote crystals; the red aplites with pistachio green epidote, of Beawar in Ajmer-Merwara and Bijapur in Jodhpur, Rajasthan; the green quartzites of the Bellary district, Mysore, Coimbatore district, Madras, and of the Hassan district in Mysore, and the garnetiferous rocks with their pale salmon-coloured to red, murchisonite feldspars of the Krishna and Visakhapatnam districts, Andhra.

ANALYSES OF MARBLE FROM INDIA AND PAKISTAN

District	Locality	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Loss	Analyst
Jodhpur	Makrana	0.98	0.16		55.10	0.39	..	T. R. Blyth
"	"	0.89	0.28		54.72	0.58	..	"
"	"	0.46	0.04		56.08	0.90	..	Mahadeo Ram
Khyber	Shahid-mena	0.02	0.10		54.60	1.61	43.86	Mahadeo Ram
Mardan	Maneri	0.04	0.05		55.86	0.33	42.58	Mahadeo Ram
"	Gundai Tarako	0.16	0.35		52.90	2.64	43.72	Mahadeo Ram

Note:—Jodhpur is in Rajasthan, India.

Khyber and Mardan are in the North-West Frontier Province of Pakistan.

CHAPTER X

MINERALS USED IN CERAMICS, REFRACTORIES AND GLASS MANUFACTURE

POTTERS' EARTHS AND CLAYS

THE prehistoric potters of India were skilled craftsmen; not only do their hand-modelled terracotta vases, 'made probably in the third millennium B.C., exhibit a high state of culture and refinement', but some of their wheel-turned, painted wares of approximately the same period show by their extremely thin walls 'the excellence and homogeneity of their paste'. Such are the opinions of the specialists Dr E. Rosenthal and Prof. Stuart Piggott. Examples range from the buff pottery of southern Baluchistan to the superb bowls of northern Baluchistan, decorated in black on buff to terracotta backgrounds; from the plain, mass-produced wares of the Harappa culture to the pots with black designs on a lustrous, deep red slip and to the rarer polychrome wares of Mohenjodaro and other sites. These early potters, too, had mastered the complexities of faience manufacture, an artificial, vitreous paste used for the glazed and coloured surfaces of beads and seals.

The potters have constituted one of the great functional castes of the Hindu social system from time immemorial and today they form the vast majority of the workers in the clay industries. They do not approach the high standards of their early ancestors but they know the essentials of their craft and satisfy the needs of the village markets, over which they hold a monopoly. 'In India', wrote H. Crookshank, 'the cheapness of his goods and the poverty of his customers will keep the potter going for many a long day.'

Any local earth, alluvial or residual, containing sufficient fluxes to make it fusible at moderate temperatures, suffices to fashion the cooking-pots, water-jars, roofing tiles, country bricks and the numerous small articles which are moulded on the wheel, dried in the sun, and baked in an open fire with the cheapest available fuel. Glazes are rarely applied, but as a substitute on ordinary ware, as V. Ball pointed out, 'mixtures of fine clay which adhere after heating are sometimes used, but they are rather in the nature of paints than true glazes, being soft and easily scratched with a pin'. Other characteristic wares of the peasant potter are the unglazed black pots of great simplicity of line which are smoked in closed kilns. As the raw materials vary greatly from place to place so do the fired products of different localities alter in colour, strength and

porosity; thus the crockery of certain places acquires a reputation due to some peculiarity in its composition. An earth from Mogul-serai, in Uttar Pradesh, contains fine mica and is said to yield a very porous ware suitable for pitchers. The tenacious clays of the Tertiary rocks of certain localities in Burma supply material for the large 'Pegu Jars', often three or four feet high, which are a speciality of Salingyi, in the Lower Chindwin valley; of villages near Kyaungmyaung, in Shwebo, and elsewhere.

The Muslim invaders of India are said to have introduced the use of glazed and decorated tiles, and to them, writes Monica Clough, 'we owe the beauties of buildings such as the Chini-karauza in Agra, built about 1639; the "Chini" or "Kashi" mosaic work was made from large plates of glazed tile cut into the required shapes for Moghul inlay work. Straightforward tiles, often with beautiful free-hand designs of figures or flowers, were used in the earlier mosques, such as Gaur tiles from the Tanti para and Lotan mosques (1475), which have a true encaustic glaze and a marked Hindu character, quite distinct from the blue and diapered tiles of distinctive Mohammedan manufacture'.

Apart from the products of the village potter, better quality wares have always been made at a few widely separated localities, most of which possess considerable merit from an artistic point of view. Amongst them are the world-famed Delhi blue vases, the red glazed pottery of Dinapore, in the Patna district of Bihar; the red earthenware of Travancore and Hyderabad; the painted pots of Quetta and Peshawar, gay with black and red designs; the black wares of Monghyr and Chunar, and the black and silvery ones of Azimgarh and Bhagalpur; the imitation *bidri* ware of Surat; the painted pottery of Kota, in Rajasthan; the gilt pottery of Amroha, in Moradabad, Uttar Pradesh; the glazed and unglazed, pressed wares of Madurai, in the far south; and the glazed pottery of various places in Sind and the Punjab.

In Burma, although there are a few villages devoted to pottery manufacture, the potter's occupation generally is a very fitful one and only pursued when agriculture does not claim his immediate attention. According to Sir George Scott, the best potters are Shans, those of the Papun district being the most noteworthy, though characteristic and elegant work is turned out in the States of Lawksawk and Mong Kung. The red and black, polished and incised wares of the latter State have a wide repute and are distributed to far distant places. Pegu is noted for its domestic pottery, cooking-pots, water-jars, goblets, flower-pots and lamps of curious shapes; Twante, in Hanthawaddy, for its glazed ware; and Tavoy for its black, porous goblets. Care and ingenuity as well as artistic skill are mainly displayed on the production of flower-vases and stands for pagodas, on alms' bowls and red, circular lamps used on festive occasions. These and similar objects come mainly from Papun, Pyinmana and Bassein. Ancient slags from lead-smelting

operations in the Shan State of Mawson are used in the preparation of glazes.

STONEWARE AND EARTHENWARE CLAYS

Plastic clays of fairly low fusibility and good dry strength, suitable for the manufacture of salt-glazed stoneware and for the coarser types of earthenware, occur in many parts and are utilized on a large scale in the modern potteries, yielding very hard, tough, partially vitrified and almost non-absorbent bodies under their glazes. The earliest pottery to manufacture such articles was established by Burn and Co. at Raniganj in 1859, but by the beginning of the century there were still only about half-a-dozen factories in the country producing earthenware and porcelain. By 1939 the number had increased to about 25, turning out a variety of ceramic goods, including electrical insulators. By 1951 the total had grown to about 40, while 7 new potteries were then under construction.

The progress of the Raniganj pottery over the course of almost one hundred years is a measure of the developments that have taken place in the industry as a whole during that time. Then, one small works made stoneware pipes, flower-pots and ornamental garden pottery: now, there are three large establishments, one devoted to the manufacture of stoneware pipes and pouring refractories, another turning out fireclay goods, and a third in which silica bricks and refractories using chromite, magnesite, sillimanite and other minerals are made. Associated with this concern are the Gulgurbari Fireclay Works at Mugma, Bihar, the Durgapur Brick Works in Bengal, and the ceramic and refractory works of Jabalpur, in Madhya Pradesh, specializing in roofing-tiles, pipes, acid-proof wares and glass pots.

This range of activities illustrates the difficulty of drawing sharp lines of distinction between the various products, for though it may be easy broadly to separate those of a pottery from those of, say, a silica-brick works, there is a gradual progression from one type of ceramic ware to another, from clay to terracotta, from stoneware to porcelain. Stoneware is said to differ from refractory ware in that it contains more fluxes, and from porcelain in that the main raw materials are plastic clays and not kaolins.

In a list of the various works using Indian clays and refractory materials we have indicated briefly the sources of the raw materials used, and to supplement this the following notes are added. The raw material of the Raniganj potteries is a dark grey, carbonaceous clay, occurring as a nearly flat seam in the Upper Coal Measures near Ronei. The Jabalpur potteries utilize white and pale grey clays of Upper Gondwana age, occurring near Chota Simla, while those of Katni use clays derived from rocks of Purana age. Clays supplying the Than potteries of Saurashtra, as well as those of

Secunderabad, in Hyderabad, are also associated with Upper Gondwana rocks, while the stoneware made at Trivellore, in Chingleput, Madras, is fashioned from low-fusible clays obtained for the most part locally. The Ranipet Potteries, in North Arcot, use clays of the Rajmahal Stage occurring near Sriperumbudur.

The principal types of coarse earthenware articles made in Indian factories include jugs, jars, basins and kitchen utensils of all kinds, glazed and unglazed. The stoneware products include jars of all sizes and descriptions, jugs, tea-pots, ink-pots, pipes, bends, junctions, channels, intercepting traps, gulleys, cable-covering tiles, sinks, cattle troughs, etc. The Bengal and Madhya Pradesh potteries alone have a capacity of over 30,000 tons of salt-glazed pipes per annum, the equivalent of 1,500 miles of 4-inch diameter pipes, each two feet in length. Indian salt-glazed pipes are made to British standard specifications and imports of this character have practically ceased. The fact that great cities like Calcutta and Madras use the homemade material throughout their entire sewerage systems is sufficient evidence of its quality. Exports already reach Burma, Ceylon and Malaya and could doubtless be further expanded, while the internal demand for salt-glazed pipes and sanitary ware in general will grow as the large schemes contemplated by both Central and State Governments come to be realized.

CHINA CLAYS

The better qualities of earthenware are made by firing mixtures of white-burning plastic clays, such as ball clays, china clays, quartz (or some other form of silica) and feldspar. Similar raw materials, in different proportions, are used in the manufacture of china and porcelain, though they are then selected with greater care, processed more thoroughly and fired at higher temperatures. Earthenware bodies are porous and for this reason must be coated with a glassy, impervious glaze, but porcelain and china have dense, white, vitrified bodies impermeable to water. Porcelain has been described in short as white, translucent, vitrified pottery, whereas vitreous china, though white and dense, is not translucent and is used for such products as insulators and sanitary ware.

As long ago as 1839, the Court of Directors of the East India Company in London, alarmed at the expense of supplying wares from Europe, especially to its Medical Department in India, ordered the manufacture of efficient substitutes on the spot, the primary objective being the improvement of such local products as were at that time available. Various samples of clay from Colgong, Rhotasgarh, Madras, Moulmein and even from Singapore were accordingly tested in the laboratories of the Medical College in Calcutta and experiments made in glazing them. About this time a successful pottery was established at Fatehgarh, in the Farrukhabad

district of Uttar Pradesh, where table-wares and glazed tiles were made in addition to ordinary stoneware. Another pottery was in operation between 1860 and 1864 at Patharghatta, in the Bhagalpur district of Bihar, where china wares and porcelain for scientific purposes were made. Patharghatta Hill, where kaolin is found both in weathered gneiss and in overlying seams 3 or 4 feet thick, is on the Ganga near Colgong and it is still today one of the sources of the clay for the Calcutta works of Bengal Potteries Ltd, a concern which 50 years ago produced table-wares and china ornaments using china clay from Mangal Hat in the Rajmahal Hills. A list of the many potteries using china clay at the present time is given in the table on pages 381-5.

References to deposits of china clay and kaolin are numerous enough in Indian geological literature to embarrass the compiler and it is only possible to make a selection of them here. Before doing so, however, it should be explained that although the two substances are often grouped together and although kaolin (using the term to include both kaolinite, $\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2 \cdot 2\text{H}_2\text{O}$, as well as other closely related silicates of aluminium) forms the greater part of the true china clays, their chemical composition varies considerably. Potters, therefore, finding from experience that some so-called china clays are unsuitable for their particular purposes, separate the two, with the result that though any white-burning clay may be termed a 'china clay' by them, a true kaolin must be highly refractory and should show no signs of vitrification under a temperature of 1750°C . 'Kaolin' is the principal ingredient in china and porcelain bodies. Typical white household china, for example, consists of kaolin or china clay, 50 per cent; feldspar 25 to 30 per cent, and silica (quartz or flint) 20 to 25 per cent. This is a body composition which, fired at 1400°C ., gives a vitrified, translucent porcelain, one in which all the pores in the body are filled with a glassy bond and which possesses little or no absorption. In actual practice neither china clay nor feldspar is theoretically pure. The former often contains both silica and feldspar, and the latter may contain both silica and clay, so that adjustments have to be made accordingly. As a matter of comparative interest and to illustrate the difference in the mineral composition of true porcelain and earthenware bodies, it is added that the average composition of five typical English examples of the latter shows china clay, 28 per cent; plastic ball clay, 33 per cent; flint, 28 per cent and pegmatite 11 per cent.

Kaolin has many other uses outside the ceramic industry and these are dealt with on another page. The white, compact, impure clays grouped together as the 'lithomarges', and often found at the bases of laterite exposures, are stated by some authorities to be unsuitable for pottery manufacture, owing to their lack of suspensibility in water after fine grinding. On the other hand, some special varieties of lithomarge such as those from Tikaria, in Katni-

Marwara, Madhya Pradesh, are reported to make excellent tiles and bricks though not for refractory purposes.

About a quarter of a century ago, that is during the five years ending 1928, the average annual production of china clay was 26,050 tons. The annual tonnage tends to fluctuate widely with the rise and fall of internal demand, but on the whole there has been a steady increase, shown by the fact that the average annual tonnage for the five years ending 1948 was over twice the former figure, or 58,885 tons, compared with 45,272 tons for the previous quinquennium. The output in 1949 was 42,396 tons, valued at Rs 11,73,786. Twenty years ago Madhya Pradesh headed the list of producers with 27.3 per cent of the total output, followed by Bihar and Orissa with 24.6 per cent and then by Mysore (15.3 per cent), Bengal (14.8 per cent), Delhi (9.8 per cent), with smaller amounts from Vindhya Pradesh, Madhya Bharat, Rajasthan and Madras with Andhra. For the five years ending 1948, production was distributed as follows: Bihar 39.0 per cent, Mysore 24.5 per cent, Madhya Pradesh 11.0 per cent, Orissa with the Eastern States Agencies 5.7 per cent, Madras with Andhra 3.5 per cent, Saurashtra 3.4 per cent, Rajasthan 2.8 per cent, with the remainder divided in smaller amounts between Delhi, Bombay with Baroda, Hyderabad, Travancore-Cochin, Vindhya Pradesh, Madhya Bharat, Kashmir and Uttar Pradesh.

In the Rajmahal Hills of the Santal Parganas of Bihar, kaolin has been found at many places as a decomposition product of feldspar in schists and gneisses, as well as in sandstones of Gondwana age. Such white sandstones are crushed and their kaolin content of 10 to 15 per cent recovered by washing at Mangal Hat, by the Rajmahal Quartz, Sand and Kaolin Co. Bengal Potteries Ltd derive some of their supplies from this source, where, it is estimated, at least 264,000 tons are available. Among the inter-Trappean occurrences of the Rajmahal Hills are the grey and white clays of Mirzachawki, in the Santal Parganas, where there are reserves of 435,000 tons, while other interstratified seams of white clay, 4 or 5 feet thick, are found near Hura, Dudhan, Karanpur, and Katangi, along the western margin of the Hills. Some of the best kaolin in Bihar comes from the Hat Gamaria neighbourhood of Singhbhum, where it occurs in deposits extending to a depth of 70 feet. Many other localities are known in both Singhbhum and Seraikela, most of which are in granite or rocks adjacent to it, and they are the results of pneumatolytic and hydrothermal activities contemporaneous with the intrusion. Their exploitation forms the basis of a small but flourishing mineral industry. China clay also occurs at a number of places in Manbhum, and at one of them, near Dhatara, D. R. S. Mehta has stated that the reserves are large and of good quality. The kaolin of Patharghatta Hill, a few miles below Colgong, in the Bhagalpur district, was first won in 1859 and the reserves remaining today are estimated at 950,400 tons of washed

mineral. About one million tons exist in the neighbouring Kasri Hill, where, as in the former case, they are associated with decomposed feldspathic gneisses. Small occurrences resulting from the decomposition of granitic rocks are also known at Samukhia and Satletwa, in Bhagalpur, and at Haridih and Sursu, in the Ranchi district.

In Orissa, the kaolin deposits of Keonjhar, Gangpur, Sambalpur and Koraput merit more attention than they have hitherto received, though material of good quality is being obtained from the vicinity of Karanjia and Joshipur, in Mayurbhanj, and from a deposit in decomposed granite about a mile north of Keonjhar town itself. Western Bengal has china clay deposits at Majmura, Beriathol and other places in the Bankura district, while some of the slates of the Daling Series in the Darjeeling district break down into white clays of uncertain composition. White clays mottled with iron stains, probably a weathered product of local shales, found in the neighbourhood of Agartala, in Tripura, are moderately plastic and infusible at 1380°C.

In south India, perhaps the most important deposits of china clay are those of Travancore, where there are occurrences here and there along the coast from near Changanacheri in the north to beyond Trivandrum in the south. Derived from the alteration of Archaean gneisses by the action of infiltrating ground waters, they still exhibit traces of the original gneissic banding, angular grains of quartz, specks of ferruginous matter and fine flakes of graphite. The best deposits are at Kundara, Varkala and other places where the porous, water-bearing Warkalli sandstones overlie the gneisses. The primary, kaolin-bearing material is up to 20 feet in thickness hereabouts but it becomes more and more impure with depth as it grades downwards into its gneissic basement. After suitable refining treatment the average yield of good clay is about 25 per cent. The Warkalli sandstones themselves contain independent beds of bluish, plastic clay, up to 10 feet in thickness, at Kundara and Padappakara and this material is utilized as ball clay. Deposits at Kundara and Chathanoor, in the Quilon taluk, have been worked on behalf of the Government of Travancore since 1936, producing various grades of processed clay suitable for any of the industries making use of the material. A well-equipped pottery operated in connexion with the clay works makes porcelain, sanitary and electrical wares as well as refractory products. Further expansion of the ceramic works is contemplated by the Government, while investigation of the clay deposits is in progress. China clays are widely distributed in Mysore, and the State Porcelain Factory derives its kaolin from mines at Arjunabettahalli and Gullahalli in the district of Bangalore. There are also important open-cast workings at Bageshapura, in Hassan district, and other deposits exist in the Malnad region, near Narasimharajpur, Koppa and Thirthahalli, as well as near Melkote and other places in Mysore district. A soft, alkali-rich clay

containing potash (K_2O) 6 to 9 per cent, alumina 30-33, silica 43-46, ferric oxide 2.5, magnesia 6.5 and manganese oxide (MnO) 2.67 per cent, is available in large quantities in manganese ore workings near Karekurchi and Janehar, in the Tumkur district of Mysore. It is probably an alteration product of phyllite and, according to B. P. Radhakrishna, may be of use in the ceramic industry.

Madras possesses large reserves of crude china clay in the Trivellore and Sriperumbudur taluks of Chingleput district, and in the Tindivanam and Cuddalore taluks of South Arcot, where the total reserves are said to be of the order of 25 million tons. The East India China Clay Co., of Nellikuppam in South Arcot, utilizes clay from rocks of Rajmahal age. A greyish-white, plastic clay has been worked for many years at Punyakshetram, in East Godavari district, Andhra, and is used as an ingredient in the manufacture of graphite crucibles in Bombay. China clay is also produced in the Dhône taluk of Kurnool district of Andhra and there are small deposits in Nellore, Visakhapatnam, Salem, Cuddapah and the Nilgiris. Good china clay is also to be obtained along the western coast, between Nileshwar (Pudukai) and Hosdrug, in South Kanara, and near Cannanore, in Malabar. In the latter district it is quarried near Elimala, Palayangadi and Kannapuram; in the former, near Pudukai, the Hindustan China Clay Works and other concerns have their properties.

Hyderabad possesses china clays in the Nalgonda district, while a deposit at Kamthana furnishes material for the paper mills at Sirpur. Others are known near Srirangapur and Kundrug, in the Pargi taluk of Gulbarga, and it has been claimed that the lithomarges from below the laterite blanket of the Vikarabad-Bidar plateau are suitable for ceramic and other purposes.

The occurrences of Bombay include those of Keralgi, in Belgaum; Malvan, in Ratnagiri; Honawar and Castle Rock in North Kanara, while the Koti-Ransipur works in the Sardarpur taluk, Mehsana district, Baroda, supply high-grade clay to most of the potters in the Bombay State as well as to various other kaolin-consuming industries. The washed clays of Arsoria and Eklara, in Idar, have similar uses, not only in ceramic work but in sizings for textiles and as fillers for paper, rubber, linoleum, soap and cosmetics, as well as for pastels and pencils. The clays of Junagadh, Bhavnagar and of Rajpur, near Kankavati, in Dhrangadra, Saurashtra, can be made to yield pottery materials of good quality by suitable treatment, but samples from various localities in Kutch appear to be of a lithomargic character rather than real china clays.

As a general rule, the feldspars of the Rajasthan pegmatites are rarely sufficiently altered to yield good kaolin, but those of the region south of Delhi form an exception, and there are also a number of localities, such as Buchara and Rasnu, in Jaipur, where the mineral has been won by local potters. The kaolin mines of Kasumpur, near Delhi, in altered pegmatites intrusive into

quartzites, were probably worked in the times of the Mogul emperors and today, with others at Masoodpur and elsewhere, supply the needs of the Delhi and Gwalior potteries. Gwalior, in Madhya Bharat, moreover, has its own china clays at Balakibawri and Nao-gaon. Kaolin is known to occur near Hardaspur, Dhar district, Madhya Bharat.

In Vindhya Pradesh, kaolin from Katoli is used by Oriental Potteries Ltd at Chandia in Rewa, and other deposits are worked at Majpara and Amirthi, in the Satna district. The white clays of Upper Gondwana age of the Jabalpur and Chhindwara districts of Madhya Pradesh have already been referred to. The felsitic rocks of Hithapathar and those between Jungera Malan and Bhandaritola, in the Drug district, yield white clays, as do similar rocks west of Markakassa, in Nandgaon. These clays have a good plasticity but fuse about 1400° C. The Chunar potteries of the Mirzapur district of Uttar Pradesh make use of a local clay. China clay also occurs in the Dudhi *tahsil* in the south of the same district.

Large quantities of china clay occur in the Udhampur district of Jammu, Kashmir, in beds 4 to 12 feet thick, constituting the lower portion of the Bauxite Series, which overlies the Great Limestone and underlies the Coal Measures and the Nummulitics. It is well exposed in the Chaker, Sangermarg, Salal and other areas. Underground and surface workings at Jangalgalli, begun about 1938, supply the Kashmir Potteries where ornamental tiles, insulators, porcelain and other white wares are made. Kaolin deposits have been reported to exist in the Lipa area, in Bushahr, Himachal Pradesh.

In the Punjab there are small deposits in the Mianwali and Nurpur districts; in the North-West Frontier Province, kaolin occurs in the Khyber Agency and is used by the potters of Peshawar; in Lahore a clay from the eastern part of the Salt Range is utilized. China clays are also known to occur in Hazara and Kohat, while good material of a plastic, ball-clay type is found in the Sheik Budin massif of Bannu. In Sind, china clays have been reported from the Karachi, Thar Parkar and Dadu districts; the last, in association with sandstones of Nari age, is exploited and used by the potteries in Karachi.

China clays resulting from the decomposition of granite were worked at one time at Yinnye-in, Thaton district, Lower Burma. Similar deposits are to be found in other parts of the granitic ranges of Tenasserim though they have hitherto received little or no attention.

A number of potteries now produce porcelain products in India and at some of them the most modern types of electrical and gas-fired tunnel kilns have been installed. The largest works are those of Bengal Potteries Ltd, at Calcutta, where all kinds of domestic, hotel and medical china are made, as well as high- and low-tension insulators and other electrical porcelains. Other leading makers

are Burn & Co. Ltd of Raniganj; Gwalior Potteries Ltd, specializing in coloured and painted domestic wares, glazed wall tiles and decorative articles; Sodepur Potteries, of Calcutta, where large quantities of utility domestic and hotel wares are turned out; Jayasree Potteries Ltd, Bombay Potteries & Tiles Ltd, Parasuram Potteries, Morvi, Saurashtra and the State potteries in Bangalore, Mysore and Kundara, Travancore.

ANALYSES OF INDIAN CHINA CLAYS

LOCALITY	ALUMINA	IRON OXIDE	LIME	MAGNESIA	ALKALI	WATER	SILICA		
							Combined	Insoluble	
Singhbhum* (Bihar)	36.28	0.89	0.86	0.65		11.84	44.07	4.88	
Patharghatta† (Bihar)	36.01	0.27	1.55	0.81	0.82	13.06	47.40		
Kundara‡ (Travancore)	39.18	0.33	0.08	0.19	0.33	13.73	45.78		0.31 TiO ₂
Kamthana (Hyderabad)	40.20	tr.	0.20			15.20	41.20		
Gullahalli (Mysore)	37.30	0.97	1.10	0.87	0.58	13.73	45.58		0.10 TiO ₂
Koti-Ransipur (Baroda)	38.85	0.63	0.16	0.16	0.12	14.42	44.20	0.72	0.74 TiO ₂

* Average of six samples

† " " four "

‡ " " two "

BALL CLAYS

Ball clays are fine-textured, highly plastic clays of detrital origin, greyish or dark coloured as found but which assume white or very pale tints when fired. They are often free enough from impurities to be used in their natural state, but when sandy materials are present with them they can usually be removed by washing and the use of settling tanks. These clays are said to contain more silica than refined china clay and their silicate of alumina is largely in the amorphous condition. Pipe clay is an exceptionally pure, white, siliceous ball clay once used in the manufacture of tobacco pipes. Ball clays are used in the manufacture of fine earthenware, china and porcelain, to increase the plasticity of the china clay and other ingredients of the body compositions so that they can be more easily shaped before firing, and also to add strength to them after drying.

Until the very numerous occurrences of secondary potter's clay, already located by geologists throughout India, have received more attention from ceramists than has hitherto been the case, it is impossible to distinguish separately those which properly belong to the ball clay group, and doubtless some examples already described under china clay will eventually prove to belong to it. In the List of Works using Indian Clays (p. 381), a number of localities are given from which various concerns obtain their supplies of ball clay at the present time, and a few further details are added below.

K. L. Bhola has described true ball clays from Jodhpur, Rajasthan, where they form two horizons in the Vindhyan rocks at Khajwana, Indawar and other places, as well as in the Mesozoic rocks of the Barmer-Sheo area. These clays, from a quarry at Gunga, in the Sheo district, have been marketed since 1928. Ball clays are also exploited at Ramparda, Vagadia and Bagagela in the Zalawad district of Saurashtra; at Pasegaon in the Adilabad district and at Ralepet in the Asifabad district of Hyderabad; at Koodappuzha in the Mukundapuram taluk of Cochin, at Athigathur in the Trivellore taluk of the Chingleput district of Madras and at Gadala in the Cuddapah district of Andhra. Other occurrences which merit attention include the greyish-white, plastic clays of Punyakshetram in East Godavari and Dwaraka-Tirumala in West Godavari district, Andhra; the white clays of Hastavaram in the Cuddapah district of Andhra; certain clays below the Tertiary rocks at Kundara, Travancore and the plastic clays of the Lakhampur forest, Banda district, Uttar Pradesh.

Ball clays are known to occur in the Bannu district, North-West Frontier Province, Pakistan.

THE TRADE IN CERAMIC PRODUCTS

In the following table the average annual values of imported earthenware and porcelain goods, as well as tiles of all kinds together with firebricks, are shown for the years between 1903 and 1939. They reached their maximum of over Rs 1 crore per annum in the decade 1919-29, falling to an annual average of about Rs 69 lakhs over the decade preceding the second world war. At that time, in so far as pottery is concerned, the imports in 1938-9 consisted of whiteware, valued at Rs 30,39,000 and weighing approximately 11,000 tons; porcelain insulators, Rs 13,50,000 and 650 tons; sanitary ware, Rs.8,80,000, and white, glazed tiles Rs 13,76,000.

The imports were derived mainly from the United Kingdom and Japan and as the war developed the trade came to a standstill. During its continuation the production of the Indian potteries increased greatly, whiteware from approximately 2,000 tons in 1939 to 5,640 tons in 1945, and insulators and stoneware from 2,200 and 4,500 tons to 8,300 and 5,400 tons respectively, in the same

period. The Panel on Refractories and Ceramics, reporting in 1948, recommended an increase, above the 1946 production, of 100 per cent in the output of whiteware and stoneware jars, and of 75 per cent in the output of insulators, to be attained at the end of 5 years, adding at the same time the following caution: 'We feel, however, that unless the industry takes steps to improve the present quality of its manufacture, especially of pottery and to some extent of insulators, the chances of development or expansion are not very bright. With its present quality of manufacture, there is very little chance for the industry to stand the competition of foreign goods which may be imported in large quantities in the near future.' Amongst the many recommendations of the Panel to bring into effect its desirable ends, none is more important than the proposal that all raw materials, clays, feldspar and quartz, should be properly cleaned, sorted, processed and standardized. After the war, imports began to reappear in the Indian markets, and for the three years ending 1950-1 earthenware and porcelain goods alone had attained a total annual average value of Rs 39,31,700 once more.

The inauguration of the Central Glass and Ceramic Research Institute in August 1950, as well as the activities of the Indian Ceramic Society, should assist in due course the potteries not only to satisfy the home demand, but to build up an export trade in whitewares as the terracotta manufacturers of Malabar and Mangalore have already done in the case of their own particular products.

AVERAGE ANNUAL VALUES OF CERTAIN CLAY PRODUCTS
IMPORTED INTO INDIA, 1903-39
(in Rupees)

	EARTHENWARE AND PORCELAIN	EARTHENWARE PIPING	BRICKS AND TILES
1903-4 to 1907-8 ..	34,42,920	1,29,720	8,01,615
1908-9 to 1913-14 ..	51,44,745	91,800	15,54,765
1914-15 to 1918-19 ..	47,01,060	1,37,985	20,89,065
1919-20 to 1923-4 ..	78,10,062	1,66,708	36,90,782
1924-5 to 1928-9 ..	76,06,875	1,51,958	26,12,155
1929-30 to 1933-4 ..	50,71,415	16,362	17,48,020
1934-5 to 1938-9 ..	45,27,800	2,400	14,88,400

FELDSPAR

The feldspars are the most abundant of the rock-forming minerals and comprise a group of silicates all of which contain aluminium and various other constituents, chiefly potassium, sodium or calcium or mixtures of these elements. The commercial varieties are more or less confined to the species orthoclase, microcline

LIST OF WORKS USING INDIAN CLAYS, REFRACTORIES, ETC.

(incomplete)

Name and Situation of Concern	Articles made	Sources of Raw Materials
Bengal Firebrick Co., Kulti, Burdwan, W. Bengal	Firebricks, pipes, etc.	Local fireclays
Lal Koti Silica Works, Raniganj, Burdwan	Refractory goods ..	See text, p. 409
Raniganj Pottery Works, Raniganj	Stoneware & pipes ..	" " p. 371
Bengal Potteries Ltd, Calcutta	Pottery of all kinds ..	" " p. 373
Calcutta Porcelain Works	Insulators, sanitary ware, crockery	China clay from Rajmahal, Kendposi, and Simultala
Sodepur Potteries, Calcutta	Porcelain, crockery ..	Clay from Jadar (Ahmenabad), Sondimra, Kendposi. Fireclay from Rajhara & Sitarampur. Quartz from Bahalda Road, Barakar and Haludpukur. Feldspar from Barakar and Jagdishpur. Flint from Taljhari
G. E. Esaw, Hooghly	Hollow bricks & tiles	River silts
Bihar Firebricks & Potteries Ltd, Mugma, Manbhum, Bihar	Refractory goods, fire cements, etc.	Fireclays from Mugma, Ramgarh, Jharia, Katras & Raniganj. Bauxite from Katni.
Bengal Bihar Firebrick & Pottery Works, Mugma	Firebricks	Fireclays from Raniganj
Bharat Firebrick & Pottery Works, Jharia, Manbhum	Firebricks	Fireclay from Jharia
Gulfulbari Firebrick Works, Manbhum	Firebricks & tiles ..	Local fireclays
Jauhar Firebrick & Refractory Works, Mugma	Firebricks	Fireclays from Raniganj
Jharia Firebrick & Pottery Works, Jharia, Manbhum	Firebricks	Local fireclays
Kumardhubi Firebrick & Silica Works, Manbhum	Firebricks, silica bricks and kyanite refractories	See text, p. 409
Reliance Firebrick & Pottery Co. Ltd, Chanch Barakar, Manbhum	Firebricks, fireclay mortars & cements. Acidproof bricks & cements	Fireclays from Raniganj, Jharia & Rajhara. Bauxite from Katni & Niwar
Jubbulpore Pottery Works Ltd, Madhya Pradesh	Firebricks & stoneware	Local clays

LIST OF WORKS USING INDIAN CLAYS, REFRACTORIES, ETC.

(incomplete)—*contd.*

Name and Situation of Concern	Articles made	Sources of Raw Materials
Perfect Pottery Co. Ltd, Jabalpur, Madhya Pradesh	Stoneware pipes & refractories	Local fireclays & bauxite
Ceramic Industries Ltd, Chanda, Madhya Pradesh	Stoneware	Clays from Ballarpur
Central Potteries Ltd, Nagpur, Madhya Pradesh	Stoneware & crockery	Clay from Shemda, Katol <i>tahsil</i> . China clay from Bhandak, Warora <i>tahsil</i>
Associated Cement Co.'s Katni Potteries, Madhya Pradesh	High alumina refractory bricks for cement kilns, boiler & cupola bricks	Fireclays from Bhaganwara, Murwara <i>tahsil</i> & Badwar in Vin-dhya Pradesh. Bauxite from Tikuri, Murwara <i>tahsil</i>
Oriental Potteries Ltd, Chandia, Shahdol, Vin-dhya Pradesh	Refractory goods ..	Local fireclay
Ishwar Industries Ltd, Delhi	Firebricks, stoneware pipes, fire cement & magnesia compositions	China clays from Masoodpur, near Delhi. Magnesite from Salem
Gwalior Potteries (Delhi) Ltd, Delhi	Stoneware jars ..	Local clays
Shivraj Pottery Works, Humayunpore, Delhi	Refractory goods ..	Fireclays from Mehpalpur, Delhi
Kesar Pottery Works, New Delhi	Stoneware, crockery & refractories	China clay & fireclay from Masoodpur, near Delhi; Than-gadh, Saurashtra & Kendposi, Singh-bhum. Quartz from Dausa, Ajmer & Lad-pura, Alwar
Gwalior Potteries Ltd, Gird, Madhya Bharat	Stoneware pipes, crockery, etc.	Clay from Belakibawri and Kusumpura, Delhi. Quartz from Gwalior & Rajas-than
Bombay Potteries & Tiles Ltd, Bombay	Glazed tiles, pottery & sanitary ware, elec-trical insulators & refractories	China clay from Kun-dara, Travancore & Thangadh. Talc from Udaipur. Quartz from Godhra, Panch Mahals

LIST OF WORKS USING INDIAN CLAYS, REFRACTORIES, ETC.

(incomplete)—*contd.*

Name and Situation of Concern	Articles made	Sources of Raw Materials
Parshuram Pottery Works Co. Ltd, Thangadh, Zalawad, Saurashtra	Stoneware jars, sanitary ware, crockery, etc.	Local fireclays from Amrapur, Bagagala & Kerwali
Parshuram Pottery Works Co. Ltd, Morvi, Saurashtra	Refractories, stonewares, crockery, etc.	Ball clay and fireclay from Rafaleswar, Makansar and Udepur in Saurashtra. China clays from Vijapur & Jadar in Idar & Kundara (Travancore)
Parshuram Pottery Works Co. Ltd, Dhrangadhra, Saurashtra	Crockery	China clay from Vijapur, Gujarat and Kundara, Travancore-Cochin
Parshuram Pottery Works Co. Ltd, Wankaner, Saurashtra	Glazed tiles, firebricks and stoneware	Fireclay from Thangadh and Wankaner China clay from Vijapur, Jadar, etc. in Gujarat Feldspar and quartz from Nasirabad, Beawar and Mangaliawas in Ajmer-Merwara
Digvijay Tiles & Potteries Ltd, Jamnagar, Saurashtra	Crockery	China clay from Vijapur, Gujarat Ball clay from Vagadia Feldspar and quartz from Nasirabad, Beawar, Mangaliawas, etc. in Ajmer-Merwara
Digvijay Tiles & Potteries Ltd, Vagadia, Saurashtra	Sanitary ware, stoneware and refractories	Fireclay from Vagadia
Ceramic & Lime Industries Ltd, Hyderabad	Bricks	Local silts & clays
Charminar Pottery Works, Mettuguda, Atrabalda, Hyderabad.	Firebricks, stoneware pipes, etc.	Clays from Asifabad, in Adilabad district
Hyderabad Potteries Ltd, Secunderabad	Firebricks, stoneware pipes, tiles, etc.	Local clays and clays from Asifabad
Pragati Pottery Industries, Betamcherla, Kurnool, Andhra	Stoneware	Clays from Mahanadi
Government Ceramic Works, Gudur, Nellore, Andhra	Sanitary ware, crockery	China clay from Kundara, ball clay from Bhimadole. Quartz from local mica mines

LIST OF WORKS USING INDIAN CLAYS, REFRACTORIES, ETC.

(incomplete)—*contd.*

Name and Situation of Concern	Articles made	Sources of Raw Materials
India Ceramics Ltd, Nellore, Andhra	Sanitary ware, crockery, etc.	China clay from Kundara, fireclay from Bhimadole (W. Godavari), quartz from Gudur mica mines
Stoneware Pipes (Madras) Ltd, Chingleput	Stoneware pipes, sanitary ware, porcelain	Low-fusible clays from Adigathur, near Trivellore & Urampadu (Cuddapah). Fireclay from Tindivanam, S. Arcot. China clay from Kandara. Quartz from Gudur
East India Distilleries & Sugar Factories Ltd, Ranipet, N. Arcot, Madras	Stoneware, acid jars, crockery, etc.	Clays from various localities in Madras. China clays from Travancore
Dalmia Cement Ltd, Dalmiapuram, Tiruchirappalli, Madras	High alumina bricks, fire cements, boiler bricks, etc.	Fireclay from Panruti, near Cuddalore
Commonwealth Trust Ltd, Kozhikode, Malabar, Madras	Flower-pots, water-coolers, etc.	Silts and clays
Calicut Tile Co., Feroke, Malabar	Tiles, roofing ridges, crockery, etc.	Silts and clays from within 10 miles of the works
Feroke Tile Works, Feroke, Malabar, Madras	Tiles, firebricks, glazed stoneware, pipes, etc.	Silts & clays from the Mamally river in Ernad and Calicut taluks
Standard Tile & Clay Works, Feroke, Malabar, Madras	Tiles, ridge tiles, etc.	Local silts and clays
A. Albuquerque & Sons, Mangalore, S. Kanara, Madras	Tiles, stock bricks, terracotta articles, hollow bricks	Silts from the Gurpur and Nethravathi rivers
Firebricks & Potteries Ltd, Yesvantpur, Bangalore, Mysore	Firebricks and tiles	Fireclays from Peenya & Malur. Ball clay from Yesvantpur
Government Porcelain Factory, Bangalore, Mysore	Porcelain crockery ..	China clay from Kundara. Ball clay from Hebbur. Quartz from Peenya
Mysore Stoneware Pipes & Potteries Ltd, Chikabanasar, Bangalore, Mysore	Firebricks, stoneware, sanitary ware	China clay & fireclay from Allalsandra, Yesvantpur & Karekurchi

LIST OF WORKS USING INDIAN CLAYS, REFRACTORIES, ETC.

(incomplete)—*concl.*

Name and Situation of Concern	Articles made	Sources of Raw Materials
Standard Brick & Tile Co. Ltd, Yelahanka, Banga- lore, Mysore	Firebricks, tiles, etc.	Local silts and clays
Kolar Brickmaking Co. Ltd, Marikuppam, Kolar, Mysore	Refractories, labora- tory ware, etc.	Clays from Malur and Hoskote. Bauxite from the Shevaroyrs. Kyanite from Mysore
Asramam Tile Works, Quilon, Travancore- Cochin	Tiles, bricks, etc. ..	Silts & clays from Ithicarai, Kallada & Karunagapally, in Quilon district
Government Ceramic Con- cerns, Kundara, Travan- core-Cochin	Refractories, porcelain crookery, electrical insulators	Local china clays. Quartz from Mana- parai in Tiruchira- palli
Quilon Tile Works, Harri- son & Crossfields Ltd	Tiles, bricks, earthen- ware, water-coolers, filters, etc.	Silts and clays from Ithicarai, Kallada & Karunagapally in Quilon district
Ithikara Tile Works, Quilon	Tiles and bricks ..	Local silts and clays
Standard Pottery Works Ltd, Alwaye, Cochin	Firebricks, tiles, stone- ware pipes, terra- cotta wares, croc- kery, etc.	Local silts and clays. China clay from Kundara. Quartz from Manaparai in Tiruchirapalli

and albite; the two former being potassium aluminium silicates with the same formula, $K_2O \cdot Al_2O_3 \cdot 6SiO_2$, and the latter the corresponding sodium aluminium silicate $Na_2O \cdot Al_2O_3 \cdot 6SiO_2$.

Feldspar is the principal ceramic flux and is employed in the fabrication of most types of ceramic wares; larger amounts, however, go into the manufacture of glass (bottles, window, plate and opalescent glass as well as glass-wares), while enamelled articles also contain large quantities of the mineral. The world's production of feldspar in pre-war years had reached half a million tons per annum and has undoubtedly increased since that time, though reliable later figures are not available. In the United States of America, in 1939, the glass industry consumed 53 per cent of the home-produced and imported feldspar, the pottery makers took 34 per cent, enamel manufacturers 11 per cent for sanitary ware, household utensils and coating sheet iron, while the balance was used for scouring soaps and cleansers, sweeping compounds and mild abrasives. In Canada, 98 per cent of the 1945 production went to the glass, pottery and enamel manufacturers.

The translucency of good porcelain is due to its feldspathic content, for on firing this commences to melt at temperatures above

1200° C. before the other constituents of the body—kaolin, white-burning ball-clays and quartz—and in so doing forms a viscous solvent for them. For the same reason it is utilized in the preparation of glazes for pottery, chinaware, earthenware, tiles and similar articles. The glassmaker requires feldspar mainly on account of its alumina content. Nepheline syenite, consisting essentially of the feldspathoid mineral nepheline $3\text{Na}_2\text{O} \cdot \text{K}_2\text{O} \cdot 4\text{Al}_2\text{O}_3 \cdot 9\text{SiO}_2$ and alkali feldspar is also mined in Canada for the glass works and potteries, as it contains 20 to 30 per cent of alumina compared with 17 to 20 per cent in the feldspars mentioned, while its higher alkali content reduces its melting temperature.

Most feldspar has been won in the past from granitic pegmatites, but coarse-grained granites are now also made to yield the mineral, which is separated, after crushing, from the quartz and mica content by froth flotation, a method also employed for the improvement of low-grade, impure, hand-mined rock.

Feldspar has been produced on a small scale in Rajasthan for a number of years and supplied to the potteries and enamel works of Delhi, the former state of Gwalior (in Madhya Bharat), Saurashtra and Bombay. In Mysore, potash feldspar containing about 13 per cent of potash (K_2O), compared with a possible theoretical content of 16.9 per cent, is obtained from a large pegmatite vein at Shettihalli, near Chikbanavar, for the State Porcelain Factory at Bangalore. These works have other sources of supply at Krishnapur in Hassan district, Thondebhavi in Bangalore, Katteri in Mysore district and at Kamasandra in Kolar.

Feldspars are present in most of the mica-bearing pegmatites of Ajmer-Merwara and of Mewar and Alwar in Rajasthan, and as a general rule form much of the bulk of the rock, often as large crystals of microcline embedded in the quartz cores of the veins, or in masses abutting against them, or, again, as quartz-feldspar intergrowths enwrapping these cores. Where there are no quartz cores their places may be taken by large idiomorphic microclines with interstitial quartz or albite. Other types of the pegmatites consist of quartz-albite intergrowths. Petrological investigations and chemical analyses prove that the normal Rajasthan feldspar, in both its white and pink varieties, is a microcline-perthite (an intergrowth of microcline and albite). At the same time albite itself is quite common alone, though in crystals smaller than those of the average microcline, and generally much intergrown with quartz. These intergrowths are ignored in existing mining operations, which aim rather at the recovery of large, quartz-free masses of microcline. The mineral is won at numerous localities around Beawar, in Ajmer-Merwara; near Khairthal and Tatarpur, in Alwar and from others in Jodhpur and the former state of Sirohi (partly in Rajasthan and partly in Bombay). In the opinion of Dr H. Crookshank, Rajasthan possesses unlimited reserves of feldspar, though only those pegmatites within a few miles of a railway station

can be worked profitably under existing conditions. Feldspar from the dumps of the Rajasthan mica mines is also sometimes collected for sale.

Microcline-perthite occurring in the pegmatites of granites is exploited on the borders of the Burdwan and Santal Parganas districts of West Bengal and Bihar, in a belt of country extending from the Madhupur-Giridih branch of the Eastern Railway to the northern boundary of the Raniganj coalfield. The potteries of West Bengal obtain some of their supplies from Chittaranjan (Mihijam), near Barakar, and there are quarries at Jagadishpore and Mathroopore, in the Santal Parganas, which yield both pink and white varieties of the mineral. Soda- and potash-bearing feldspars are available on the Koderma mica field and its extension into the Chakai region of Gaya, Bihar, especially from the waste heaps of the mica mines to which constant additions are being made. The soda feldspars are the commoner varieties, and D. R. S. Mehta's recent investigations are not encouraging as far as potash feldspars are concerned. Flesh-coloured feldspars occur abundantly in the granite pegmatites of the crystalline rocks on the borders of Manbhum, Bihar and Bankura, West Bengal, while to the north of Jainti, in south Singhbhum, there are large pegmatite veins consisting almost entirely of potash feldspar. From the Sambalpur district of Orissa, B. C. Roy has described giant crystals of orthoclase and microcline, several feet in diameter, in a pegmatite at Pandri, while smaller ones are to be found at Laikhera, Laira and Gambharpalli.

The feldspar quarries of Burn & Co. at Lameta Ghat in the Jabalpur district of Madhya Pradesh have been in operation since 1904, and their products not only supply the potteries of Jabalpur but are widely marketed in other parts of India, in both the processed and semi-processed condition. Feldspar has also been quarried since 1941 at Borgaon and since 1948 at Lodhikhera, in the Chhindwara district of Madhya Pradesh. Feldspar quarries have been opened within recent years at Dokava, near Godhra, in the Panch Mahal district of Gujarat, Bombay. The deposits are described as fairly rich and capable of meeting the growing demands of the ceramic industry in that part of the country.

The commonest feldspar of the pegmatites of the Nellore mica belt of Andhra is white perthite, followed by pink orthoclase in which the perthitic streaks are not so closely spaced together, while a green perthitic microcline is occasionally found. The partially kaolinized feldspars of some of the mica mines would, as Dr M. S. Krishnan has pointed out, serve as a substitute for Cornish Stone, so largely used in the English trade for the manufacture of earthenware, porcelain and bone china. The decomposed pegmatites from Lingapuram, as well as those of the Yerravaram reserved forest, about 5 miles from Narasapatnam, in the Visakhapatnam district, would in all probability serve a similar purpose.

V. S. Swaminathan has stated that the quantities of feldspar available in Nellore and some parts of Mysore are enormous. Potash feldspars have been won since 1942 at Chettiyapatti and Vengaikurichi, villages near Manaparai, in the Kulitalai taluk of Tiruchirapalli district of Madras for use in the ceramic industry of southern India. Finally, Hyderabad has its own deposits at several places in the districts of Raichur, Mahbubnagar and Gulbarga.

Feldspar has appeared regularly in the Mineral Returns since 1930, and up to 1933 the average annual production was 388 tons; during the next quinquennium, 1934-8, it rose to 658 tons, over 90 per cent of which came from Rajasthan and Ajmer-Merwara, mainly from the latter. In the post-war quinquennium, 1944-8, the annual average had increased to 933 tons, valued at Rs 10,226, and in this period Rajasthan, with 36.6 per cent of the total, yielded the first place to Madhya Pradesh with 42.1 per cent, mainly from the Chhindwara district. Smaller quantities came from the Hassan district of Mysore, the Tiruchirapalli district of Madras, Rewa in Vindhya Pradesh and the Burdwan district of West Bengal. In 1949 the output was 849 tons, valued at Rs 11,101.

ANALYSES OF INDIAN FELDSPARS

	1	2	3	4	5	6	7	8
SiO ₂	64.18	67.10	64.77	65.87	64.42	64.00	66.69	67.26
Al ₂ O ₃	19.46	20.44	18.94	18.84	16.42	18.03	17.40	20.09
Fe ₂ O ₃	0.12	0.10	0.09	0.05	0.32	0.67	0.72	0.22
MgO	0.26		0.15					0.34 (TiO ₂)
CaO	0.10	0.08	0.16	0.38				0.30
Na ₂ O	3.02	11.62	2.67	11.50	3.96	3.30	3.29	10.12
K ₂ O	12.62	0.24	12.28	2.93	14.48	13.99	12.04	0.12
Loss		0.40	0.43	0.40			0.12	1.16

1. Flesh-coloured feldspar from Chhindwara, used in the Jabalpur potteries. Analyst, E. Spencer.
2. Albite from Koderma. Analyst, E. Spencer.
3. Pale pink feldspar from Sedria, Beawar, Ajmer-Merwara. Analyst, A. Nadel.
4. White feldspar, Lohagal, Ajmer-Merwara. Analyst, A. Nadel.
5. Feldspar from L. N. Mine, Nellore, Andhra. Analyst, V. Swaminathan.
6. Feldspar from Narupur, Nellore, Andhra. Analyst, V. Swaminathan.
7. Feldspar from Krishnapur, Holenarsipur taluk, Hassan district, Mysore. Mysore Geological Survey.
8. Soda Feldspar from Lameta Ghat, Jabalpur, Madhya Pradesh. Burn & Co.

QUARTZ

Quartz, the oxide of silicon, SiO₂, is the commonest mineral in the earth's crust after the members of the feldspar group, forming the greater part of the sandstones and quartzites as well as the sands

of the sea shore and river valleys. Most granites contain over one third of their weight of quartz and it is present in many other igneous rocks. It is the source of the element silicon, itself a constituent of many ferrous and non-ferrous alloys, while its compounds include many of great industrial importance such as silica gel, water-glass, the carbide (carborundum) and the silicones. Besides the uses of silica for abrasive, refractory and absorbent purposes (as in the manufacture of dynamite), and for commoner applications, such as concrete and mortar mixtures, artificial stone, sand stowing, filtering and moulding purposes, etc., it is an essential raw material for the glass manufacturer and for the potter, especially in the preparation of earthenwares and porcelains. In six typical English earthenware bodies the proportion of silica (flint) ranges between 22 and 38 per cent, while hard porcelain for table-ware may contain from 20 to 25 per cent. Silica is used in potteries either in the form of sand, sandstone, quartzite, flint or quartz. English potters are said to prefer silica in the form of calcined flint, whereas in other countries sand, properly crushed and purified, or quartz, reduced to powder, is in more general use.

Sands and sandstones suitable for glass manufacture are described separately, and in many of the regions occupied by the crystalline rocks, quartz veins exist which are capable of supplying material almost completely free from impurities. The pegmatite veins mined for mica in Bihar and Andhra, and for mica, beryl and feldspar in Rajasthan, contain great quantities of quartz buried in the spoil heaps of the workings. Dr H. Crookshank has stated that in Rajasthan quartz is available in any quantity or degree of purity that might be required. The potteries of Delhi and the glass works of Agra alike obtain their supplies from Dausa in Jaipur. The mineral has also been quarried for the past ten years at Nundri Maldeo, in Ajmer-Merwara. In Bihar, large quartz veins occur in the Singbhum granite and others are known in the Ranchi, Manbhum, Hazaribagh, Santal Parganas and Monghyr districts. Quarrying operations in pegmatites, undertaken primarily for their feldspar content, often work quartz as a by-product; in this way it is won and marketed from the Jagadishpore and Mathroopur quarries of the Dumka area, in the Santal Parganas, and from those of Lameta Ghat, in the Jabalpur district of Madhya Pradesh. Quartz of special purity has been observed in veins around Jhar-saguda, Rengali, Gumlai, Naikpara and Parmanpur in Sambalpur and in the adjoining areas, while from the vicinity of Dalapur, in Koraput, Orissa, Dr A. K. Dey has described practically pure and easily crushed quartzites. The Government Porcelain Factory at Bangalore, Mysore, obtains its supplies of quartz from mines at Peenya, near Yesvantpur, 3 miles away. The only impurities in this quartz are 0·21 per cent ferric oxide and 0·58 per cent alumina. The Mysore Glass and Enamel Works quarry their own supplies at Sonnehalli, near Kengeri, Bangalore district.

Silica melts in the oxy-hydrogen blowpipe to a colourless glass-quartz glass, which has an extremely low coefficient of thermal expansion, so that it can be rapidly cooled without cracking. It is used in the construction of articles, such as laboratory ware, in which resistance to sudden changes of temperature is desirable. True glasses resistant to similar thermal shocks contain notably high amounts of silica and are increasingly used for oven and domestic ware. Quartz glass is used for the manufacture of fibres and threads employed for suspension purposes in delicate electrical and other instruments. Quartz wedges are used for the determination of certain optical properties of minerals in polarized light. Both transparent and opaque fused quartz products are made on a large scale. The best optical qualities of the former, such as those required for lenses, prisms, etc., are manufactured from selected quartz crystals, calcined and ground into powders which are then fed into special oxy-hydrogen blowpipe furnaces and built up into small billets. The normal qualities are made up into tubing, chemical apparatus and quartz wool for high-temperature insulation. Non-transparent silica tubes or pipes are formed from selected sands (99.7 per cent silica) in steel rotating furnace tubes, heated progressively by an electric arc. Crucibles, basins, etc., are preshaped and then progressively sintered and fused in another type of furnace by the same means. The purest natural varieties of quartz, known as rock crystals, have important industrial applications dependent on their piezoelectric properties; others are valuable as semiprecious stones. Both of these are treated separately.

Silicon carbide, or carborundum, SiC , produced by the fusion of mixtures of sand and coke in electric arc furnaces, is one of the more important abrasives as it is nearly as hard as the diamond, but it is also widely employed as a refractory material. It has high thermal conductivity (four to eight times that of fireclay) and only decomposes towards 2000°C . in a reducing atmosphere. Bonded with clay it is made into bricks and shapes by the various methods employed in the ceramic industry. It is used in the construction of saggars and other kiln furniture, for the muffles of muffle ovens, etc., after being fired at temperatures of 1400°C . to 1600°C . Carborundum rods are also utilized as resistance heaters in industrial furnaces; carborundum bricks (which often contain 85 to 90 per cent of the carbide), conduits and condensers, in the construction of zinc smelting retorts; and carborundum pots in the melting down of gold bullion, because of their mechanical strength, ability to withstand successive heating and cooling, freedom from internal flaws and ease of scraping.

Quartz fused with sodium carbonate (soda ash) yields the water-soluble silicate of soda, Na_2SiO_3 , or water-glass, and when a solution of this is treated with hydrochloric acid a very voluminous, gelatinous mass separates out which is known as silica gel, $\text{SiO}_2 \cdot n\text{H}_2\text{O}$; on drying it forms a fine, white, amorphous powder. Silica

gel possesses the remarkable property of absorbing water and is used for the dehydration of industrial gases. It can also adsorb substances from solution, such as sulphur from petroleum products.

By heating the precipitated silica gel under pressure at high temperatures, colloidal dispersions of silica in water are obtained, and when dried out, films of this amorphous silica prove to have lost the original abrasive character of the mineral and to have developed marked frictional properties. Such silica sols have various applications in industry, especially in woollen mills, for their application to loose wool before its processing causes an increased drag between the fibres during spinning, resulting in a stronger fibre, fewer breakages of the yarn during spinning and weaving, greater operational efficiency and better wearing qualities in the finished cloth. Silica sols are also employed in the processing of rayon, nylon and glass fabrics and in the preparation of floor polishes to give slip-resistance.

Amongst the organic compounds of silicon, the silicon esters are important, for some of them are easily reconverted into silica in the presence of water. Ethyl silicate, for example, is a colourless, mobile liquid which is used to impregnate stone, cement, plaster or similar materials, the pores of which it fills with glassy silica and so renders them weather- and water-proof. By mixing ethyl silicate with refractory powders, or high-grade ceramic aggregates, workable bodies of exact composition are obtainable which do not shrink during drying and firing, points of particular importance in the preparation of moulds for precision castings. Ethyl silicate is also used in the manufacture of fluorescent lighting tubes, to supply an adhesive coating of silica between the glass and the fluorescent pigment, and, again, to give an internal coating of silica for 'frosted' electric light bulbs. Some of the more stable silicon esters, the aryl and higher alkyl silicates, are said to show promise as liquid media for heat-exchange and hydraulic systems.

The silicones are defined as polymeric organosiloxanes of the general type $(R_2SiO)_n$, where R may be one of many hydrocarbon radicals. One method of their manufacture starts with silicon tetrachloride, $SiCl_4$, a colourless liquid obtained when an intimate mixture of quartz and carbon is heated in a stream of chlorine. The next step is the replacement of one or more of the chlorine atoms by organic radicals; the resultant organosilicon chlorides are hydrolysed to silanols which condense into the polysiloxanes or silicones. According to Dr J. A. Gardner, to whose recent writings we are indebted, the foundations of organosilicon chemistry were laid by the English chemist Kipping in the years 1899-1944, but it was only during the last war that their value really became apparent, mainly as the result of work by American chemists, and it was not until about 1943 that silicones generally came into industrial prominence. Today they are obtainable as a new class of inert liquids, greases, rubbers and resins, characterized

by high thermal stability, water-repellent properties and electrical resistance. The fluid silicones are of value as hydraulic liquids and as lubricants to operate in extreme cold, as they remain mobile below -100°F. , which accounts for their use in aircraft flying at high altitudes. They prevent surfaces from sticking together and are valuable as mould release agents, whether it be from the tin of the bread baker or the intricate patterns of the rubber manufacturer. They are employed commercially in the waterproofing treatment of nylon, acetate rayon and other fabrics, as well as on porcelain electrical insulators liable to be covered with films of condensed water. As foam suppressors they are utilized in the paper, textile, brewing and other industries, where foaming is liable to occur. Silicone films are chemically inert and like some of the natural silicates resist deterioration on prolonged exposure to weathering, properties used to advantage in the manufacture of car finishes, furniture polishes and so forth. By suitable treatments the liquid silicones can be processed into silicone greases, resins and rubbers. The former do not melt when heated and are resistant to oxidation and the action of acids and alkalis. The resins can be used in the liquid condition as impregnating agents which on baking withstand the action of heat or water to a far greater extent than ordinary varnishes, and as they also possess good dielectric strength, are employed extensively in the electrical industry as insulating materials. It is also possible, states Dr Gardner, 'to formulate paints, based on the resinous silicones, which will withstand temperatures up to 1000°F. '. Synthetic silicone rubber is said to resemble and behave like rubber though it is deficient in resistance to tension, tear and abrasion; at the same time, as it remains flexible and elastic over a temperature range of -100°F. to 400°F. , it is employed with success as a gasket material and for insulation in electrical devices where resistance to thermal ageing is essential. Such devices include motors operating in mines, in moist atmospheres and high temperatures.

FIRECLAYS

Fireclays are one of the foundations on which industry rests as their products are to be found in every stove, furnace or kiln where high temperatures are generated. 'Although it may be possible to build houses with bad or indifferent bricks,' wrote V. Ball in 1881, 'it is quite impossible to carry on many metallurgical and other processes continuously without the aid of durable and refractory firebricks.' Thus, in early British times in India, firebricks of known brands were imported from abroad for use in the country in spite of their high prices. In 1875, however, experimental firebricks made at the Raniganj potteries of Burn & Co. Ltd (established in 1859), were tested by officers of the Geological Survey of India in the furnaces of the Calcutta mint, where several

of them stood the tests perfectly, showing no signs of cracking or vitrification; subsequently such bricks were used in the blast furnaces of the Bengal Iron Works Co. (1874-9).

For many years the products of Burn & Co., the only concern specializing in the work in India, were supplied for blast furnaces and foundries, for the settings of gas retorts, for the cupolas of the railway workshops and so forth. As a result of the foundation of the Tata Iron & Steel Works in 1904, the demand for firebricks and other refractories rapidly increased, and today there are over twenty firms engaged in their manufacture, though most of them are small and the five leading companies turn out about three-quarters of India's total annual production, estimated at over 200,000 tons of refractories of all kinds. This would represent about 50 million standard bricks ($9 \times 4\frac{1}{2} \times 3$) if the whole production were of firebricks alone, though actually the total of 200,000 tons includes other products made from silica, magnesite and chromite. The leading manufacturers include Burn & Co. Ltd, The Kumardhubi Fireclay & Silica Works Ltd, The Reliance Firebrick & Pottery Co. Ltd, Bihar Firebricks and Potteries Ltd, and The Tata Iron & Steel Co. Ltd. The plants of most of the manufacturers are located in the coalfields of Bengal and Bihar—all within a radius of 50 miles of Asansol. A few works, however, have been established in other parts of the country, especially in Madhya Pradesh and Mysore, primarily to meet local demands. Indian cement and glass makers, as well as large distilleries and sugar factories, are frequently proprietors of clay quarries and potteries whence their own requirements of raw refractory materials are derived. As far as equipment, machinery, kilns and general lay-out are concerned, Indian refractory works are the equals of any others in any part of the world, and most of the larger ones produce other products in addition to various grades of normal firebricks. These include high-alumina bricks, fire-proof cements, plastic refractories, bonding materials and acid-proof bricks and cements.

The fireclays of the Raniganj coalfield are of excellent quality and the bricks made from them are equal to the best foreign supplies. The facts that the Indian iron and steel works use nothing but the home-made articles, that they render efficient service in them, and that the foreign firebrick has virtually disappeared from the Indian market, are conclusive proof of these statements.

For fireclay goods in general the purer clays containing 45 to 65 per cent of silica, between 30 and 40 per cent of alumina, with low contents of iron oxide (0.6 to 1.5) and of fluxes such as lime (0.2 to 0.6) and alkalis (traces to 1.4 per cent), are used. Carefully blended mixtures of clays of such types are burnt at temperatures which may vary between 1200° C. and 1400° C. The refractoriness of the finished brick can be improved by increasing the amount of alumina it contains, though this entails firing at the

higher temperature range. Such bricks are employed under unusually exacting conditions, as, for example, in high-temperature boiler installations or the hotter zones of cement kilns. Indian brick-makers use bauxite for this purpose, obtaining it as a rule from Lohardaga, in the Ranchi district of Bihar, or from Katni, in Madhya Pradesh, and marketing their products under a variety of trade names as 'super-refractories'.

The fireclays of the Raniganj coalfield are found in numerous seams, up to several feet in thickness, within the Lower and Middle Measures of the Barakar Series, cropping out at many places from the Garphalbari-Dahibari area, about the Kudai river, in the west, to the trans-Adjai region in the east. The fireclays of the Jharia coalfield, again of variable thickness, occur mainly near Jharia itself and towards Pathardih. They are said to need careful selection and blending for successful use. The Daltonganj coalfield has supplied a highly plastic fireclay from quarries at Rajhara, in Palamau district, for over 30 years, mainly for blending with the clays of the other coalfields. The fireclays of the Rampur coalfield of the Sambalpur district of Orissa have been quarried regularly around Jorabaga, near Belpahar, since 1928, by the Tata Iron & Steel Co. Ltd, for dispatch to the works at Tatanagar. A number of other occurrences have been prospected. Similar materials probably occur in the coalfields of adjoining regions and are already known in the Korba field of Bilaspur, in Madhya Pradesh. In the Coal Measures near Dola in the Sahdol district of Vindhya Pradesh, S. K. Ghose found two seams of fireclay, respectively 17 and 7 feet thick and infusible at 1700° C. At Jagannathprasad, in the Khurda sub-division of the Puri district of Orissa, fireclays are quarried for the manufacture of fire-blocks and crucibles for use in the local glass industry.

The white clays of the Upper Gondwanas of Chhota Simla, Jabalpur, Madhya Pradesh, worked extensively for pottery, tiles and pipes, are mixed with bauxite to yield high-duty refractory articles. These clays, blended with other local ones, have also proved suitable for glass pots and tanks in the factories of Uttar Pradesh, which used to import such articles from Japan. The quarry near the North Civil Station at Jabalpur was opened in 1904, but there is another, at Tikaria in the same district, which has been producing since 1872. A glass-making concern of Jabalpur obtains its clays from Garha, near Madan Mahal, while the Associated Cement Co. Ltd work clay at Bhavnagar, near Slemabad, in the Sihora *taluk* of Jabalpur district.

Fireclays from a seam at Ratucha, near Khewra, in the eastern Salt Range of the Punjab, have been used for making firebricks by Lahore Industrials Ltd, and others are employed by Rajah Industries of Jungshani, in the Karachi district of Sind. The potters of Thangadh, in Saurashtra, manufacture firebricks from local clays, as do those of Ranipet, in North Arcot and Nellikuppam in South

Arcot, Madras. Fireclays are to be found in many of the patches of Gondwana rocks of the East Coast, as, for instance, near Sriperumbudur, in Chingleput, Madras and Vemavaram, near Ongole, in the Guntur district, Andhra.

The Mysore Geological Department works the fireclay deposits at Nandagudi, in the Hoskote taluk of Bangalore district, and in Bangalore itself there are firms engaged in the manufacture of refractories of various kinds. The Kolar Brickmaking Co. Ltd commenced operations in 1917 at Marikuppam, about 60 miles east of Bangalore, making at first extra-strong building bricks for lining the deep shafts of the Kolar gold mines. In the course of time the manufacture of refractories has become an important part of its activities. They include not only firebricks, locomotive furnace arches, cupola linings and gas-plant requisites but also crucibles, muffles, scorifiers, etc., for use on the goldfields. The refractory clays come from Karadibande, in the Kolar district, and Thinnalu in Bangalore. Refractory products are also made by various firms in Feroke (Malabar), Quilon (Travancore) and Alwaye (Travancore). A white clay from Kizhupillikkara, in the Trichur taluk of Cochin, has been used for making firebricks and saggars since 1935. A bluish white, plastic clay, free from gritty materials, known locally as *bhutada*, is quarried at Budhel and Thoradi in Bhavnagar, Saurashtra, and sold in Bombay and Ahmedabad for use as boiler lagging according to B. C. Roy.

In addition to the localities already mentioned, fireclays have been reported from many other places and some of them have been proved by experiment to be of good quality. Among such localities are the following: Jawai, in the Khasi Hills of Assam; many places on the western side of the Rajmahal Hills of the Santal Parganas of Bihar, where they are often associated with thin coal seams; at Patharghatta, near Colgong, Bhagalpur district, Bihar, interstratified with white pottery clays; the Karanpura coalfields; Kripsera, in Sundargarh, Orissa; Kundara, Travancore, at the base of the Tertiary rocks; Dalol and Rajpur, Panch Mahals, Bombay; Himatnagar in Idar; Matakri Takri in Baroda; Baglala, Kerwali, Lakhtar, Kankavati, Dholi and other places in Dhrangadra, Saurashtra; the lignite field of South Arcot, Madras; Deopoor in Kutch; overlying the coal seams in the hills south of Antargaon, and at Konasamudram, Nizamabad district, Hyderabad; Bandara and Sirol in Kotah, and near Kita and Devikot, in Jaisalmer, Rajasthan; the Chanda-Umaria region of Rewa, Vindhya Pradesh; on the southern edges of the Chikalda range, in the Betul and Amraoti districts, and on the northern slopes of the Satpuras, associated with sandstones of Cretaceous age, in the Chhindwara and Hoshangabad districts of Madhya Pradesh.

The annual average recorded output of fireclay for the five years ending 1948 was 92,000 tons, approximately, 28.6 per cent of which came from Madhya Pradesh, 25.1 per cent from Bengal,

24.5 per cent from Bihar and 16 per cent from Orissa. In 1949, 106,429 tons, valued at Rs 8,36,978, were produced. The returns are manifestly incomplete and there is strong reason to suppose that some fireclay has found its way into the 'Other Clays' of the statistical tables, in which neither china clay nor fireclay is supposed to be enumerated.

The capacity of established fireclay works in India is more than sufficient to meet existing demands, but as industrialization grows these will quickly expand; indeed the Panel on Ceramics and Refractories envisaged an increase of as much as 100 per cent within

ANALYSES OF INDIAN FIRECLAYS

LOCALITY	DISTRICT	SILICA	ALUMINA	IRON OXIDES	LIME	MAGNESIA	ALKALIS	TITANIA	LOSS
1 Gourangdi ..	Burdwan	50.48	35.06	0.64	0.33	0.20	1.13	—	12.12
2 Barakar ..	"	53.70	29.47	1.50	tr.	0.61	2.39	2.20	10.10
3 Kumardhubi ..	Manbhum	44.70	38.08	1.20	tr.	tr.	0.90	1.96	13.63
4 Patlabari ..	Jharia	53.58	30.88	0.68	0.28	0.22	1.40	—	12.98
5 Mahaldih ..	"	54.43	30.77	0.77	0.20	0.35	0.36	1.36	11.72
6 Rajhara ..	Palamau	60.02	27.65	1.20	—	0.33	0.12	1.40	9.79
7 Belpahar ..	Sambalpur	50.34	34.30	1.00	tr.	0.18	0.62	1.38	12.42
8 Jabalpur ..	Jabalpur	62.92	25.29	1.08	0.57	0.29	0.58	—	9.35
9 Durgapur ..	Chanda	60.90	23.60	4.00	1.50	—	—	—	9.00
10 Thangadh ..	Saurashtra	65.85	21.52	0.88	1.26	tr.	—	—	9.80
11 Ratucha ..	Jhelum	44.08	38.48	0.88	0.02	0.09	0.16	2.50	13.72
12 Devagonthi ..	Shimoga	48.90	39.97	0.63	0.26	—	—	—	9.60
13 Nandagudi ..	Bangalore	49.01	36.32	1.33	—	—	0.43	—	13.02
14 Tinnalu ..	"	64.66	24.89	1.38	tr.	0.19	—	0.34	8.78
15 Kundara ..	Quilon	48.40	37.05	0.30	0.16	0.01	nil	0.85	13.40
16 Lignite Field	S. Arcot	41.72	40.28	0.80	nil	—	—	—	16.62

NOTES

- Nos. 1 & 2. Typical fireclays of the Raniganj coalfield. Used by Burn & Co.
 No. 3. Typical fireclay of the Raniganj coalfield. Used at the Kumardhubi works.
 Nos. 4 & 5. Typical fireclays of the Jharia coalfield. Used by Bihar Firebricks & Potteries Ltd.
 No. 6. Fireclay of the Daltonganj coalfield. Used by Reliance Firebrick and Pottery Co. Ltd.
 No. 7. Fireclay of the Rampur coalfield. Used by the Tata Iron & Steel Co. Ltd.
 No. 8. Upper Gondwana clay. Extensively quarried for many years.
 No. 9. Gondwana clay from the Durgapur Colliery, Chanda district. Burns yellow owing to its high iron content.
 No. 10. A white clay used as a fireclay by local works.
 No. 11. A clay of Tertiary age. Associated with the Dandot coal seam.
 Nos. 12, 13 & 14. Typical fireclays from Mysore. No. 13 is used in the State potteries. No. 14 by the Kolar Brickmaking Co., Ltd.
 No. 15. Typical fireclay of Travancore.
 No. 16. A white, plastic fireclay from the lignite field of South Arcot, Madras.

a period of 5 years. There is no shortage of raw materials, for the supplies of good fireclays are capable of meeting any future calls upon them; though winning costs are likely to increase. Dr H. Crookshank believed that there is still room for small works making firebricks for local consumption in some outlying areas, to obviate high railway freights from the main manufacturing centres in Bengal and Bihar, and he included in such areas Chanda, Bikaner, Assam, Rajahmundry and Jammu. The possibilities of developing an export trade in these products, particularly with Burma, Malaya, Indonesia and countries further afield, should also be carefully investigated.

ANALYSES OF INDIAN FIREBRICKS (from W. H. Bates)

MAKER	BRAND	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Alks.	TiO ₂	TOTALS
Burn's	Standard	59·85	35·40	1·90	0·77	0·73	0·30	—	98·95
"	M. C.	59·60	38·58	2·40	0·40	0·72	tr.	—	101·70
Kumar-dhubi	Bird's	60·50	35·40	2·60	0·40	0·10	0·90	—	99·90
"	Special	48·62	43·38	3·55	tr.	0·10	1·01	3·00	99·66
Reliance	Barakar	44·38	49·02	2·56	0·15	0·38	0·23	3·50	100·22
"	Reliance	59·43	35·40	2·40	0·33	0·40	0·57	1·75	100·28

DOLOMITE

Dolomite is a carbonate of calcium and magnesium, $\text{CaCO}_3 \cdot \text{MgCO}_3$, containing when pure 54·35 per cent of the former and 45·65 per cent of the latter constituent, or, 30·4 per cent of lime, CaO, and 21·7 per cent of magnesia, MgO. It is a natural double compound and the two carbonates cannot be separated by any physical ore-dressing methods. Ordinary limestones become changed into dolomitic limestones and dolomites by the long-continued action of solutions of magnesium salts; as the molecular volume of dolomite is smaller than that of calcite, the resulting dolomite rock is porous, unless it has been later metamorphosed. The thermal metamorphism of dolomites often changes them back in part to calcitic marbles owing to the development of secondary magnesian silicates. Examples of this kind are abundant in the crystalline rocks of India, Pakistan and Burma. Sedimentary and infiltration dolomites occur in the later formations of all ages from the Palaeozoic to the Tertiary.

The crushed rock, either in its raw state or, more usually, in its shrunk or dead-burned condition, after calcination in shaft or rotary kilns, is used as a basic refractory in the manufacture of steel, in the forms of lining blocks for converters, bricks, furnace bottoms and hearths, powders and preparations for maintenance work generally. The calcined mineral, after crushing to suitable sizes, may be mixed with hot tar and rammed into its place in the hearths of steel

furnaces while still hot. Other processes use mixtures of burnt dolomite and slag, or ground material without a binding, or, again, pressed blocks of dolomite and tar mixtures, only a proportion of which have been burnt. Though less stable, more liable to disintegrate and generally not as effective as magnesite, it possesses the merit of cheapness and is used for refractory purposes in very large quantities; in the United States of America alone, sales of the dead-burnt mineral had exceeded one million tons per annum by 1941 and British consumption is stated to be more than 600,000 tons per annum. A. C. Harris of the Iron and Steel Corporation of Bengal has given the following interesting analyses in which typical Indian and British dolomites and the burnt product made from them are compared:

	Indian Dolomite	British Dolomite	Burnt Indian Dolomite	Burnt British Dolomite
SiO ₂ ..	3.7	1.5	7.5	3.5%
Fe ₂ O ₃ + Al ₂ O ₃ ..	1.4	1.5	6.0	4.3%
CaO ..	29.6	30.5	51.2	54.5%
MgO ..	21.0	21.0	32.7	36.0%
Ignition Loss ..	44.0	45.0	2.0	1.5%

At the same time some authorities favour rocks that are not so pure as these. Thus, according to Mr E. B. Hall¹ of Bird & Co., Calcutta, the dolomite should contain not more than 7 per cent of silica, 3 per cent of alumina and 6 per cent of ferric oxide; furthermore, dense, fine-grained, flinty varieties, with their impurities well distributed throughout the stone, are preferable to the coarse crystalline kinds. He adds that for satisfactory use as a fettling material, the dolomite should not be too pure, having found from actual experience that a total of 8 to 12 per cent of impurities gives the best results, though they must not exceed the latter figure. The theory is that on burning these impure rocks, glassy films of fusible silicates are formed which hold the particles of the mass together. Be this as it may, Indian steel-makers are agreed that more research is needed into means of improving the fritting properties of the available stones, and of increasing the stability of the product in the climatic extremes under which it is made, stored and used in India. One of the difficulties is that lime, limestone and dolomite, even when heated to very high temperatures—and lime itself only begins to volatilize at about 2570° C.—are not proof against hydration. It has been suggested that the addition of other metallic oxides, such as those of magnesium and chromium, to the composition of dolomite bricks might make them more stable and prevent inversion

¹ Personal communication.

during firing. In this connexion J. A. Dunn advocated experiments with the talc-magnesite rocks which occur near Bhitari Dari, south of Jamshedpur. Other uses of dolomite are described under MAGNESIUM.

The best-known Indian occurrences are in the Birmitrapur Stage, of Middle Dharwarian age, in the Gangpur anticlinorium of Orissa, where they extend from about Sukra in the east for a distance of over 60 miles, across the Ib river into Sambalpur. Both dolomite and limestone have been won from this Stage since 1898, when exploitation started around Rourkela and Bisra. The requirements of the Tata Iron & Steel Co. were obtained at one time from quarries at Amghat, but since 1918 have been drawn from others at Panposh. B. P. Byramjee & Co. quarry the stone at Usra, the Gangpur Stone, Lime and Dolomite Co. at Laing, while at Birmitrapur the Bisra Stone Lime Co. Ltd has supplied both dolomite and limestone to all the Indian iron and steel centres since 1922. At this locality alone, Dr M. S. Krishnan has calculated that 252 million tons of dolomite are available down to a depth of 150 feet, and of this quantity 84 million tons are of high-grade stone. Between the years 1912, when statistics commenced, and 1933 inclusive, over 2½ million tons of dolomite had been taken from the localities mentioned, the record year being in 1925 when 316,581 tons were removed. From 1929, however, production fell to a fraction of this amount owing, it is stated, to the replacement of dolomite by limestone as a flux in iron ore smelting by the Tata concern. Some of these dolomites are remarkably and consistently pure; thus from the Amghat quarries dispatches uniformly averaged under 2 per cent insolubles, while average shipments from Usra, over the three years 1929 to 1931, show all impurities as 2.5 per cent. Allowing for these the rocks concerned closely approximate to the theoretical composition of the mineral. Over the 17 years 1934 to 1950, inclusive, a further 992,780 tons of dolomite were quarried in Gangpur.

Of other occurrences in Gangpur the following are noteworthy: a zone with shaly partings which appears at intervals, striking north-east and south-west, under 15 to 25 feet of alluvium, for 6 miles along the Sapai river, 6 to 8 miles north-west from Dharuadihi railway station; an extensive deposit of grey, compact stone near Kukurbhuka, six miles from Sonakhan railway station, and other deposits near Khatkurbahal, Lanjiberna, Amghat and Beldih which are associated with limestones; another zone of fine-grained, massive rock is exposed at Jagdah and along the Katepur *gharia* near Patrapali. In the northern limb of the great anticlinorium, east of Birmitrapur, H. Nandi found an impersistent band some 2,000 feet long and 300 feet wide, at Purnapani. In western Gangpur (now western Sundargarh), greyish-white, saccharoidal, dolomitic marble forms a narrow band about a mile in length and up to 210 feet in width at

Lifripara, occurring again at Surgura. In the Sambalpur district, B. C. Roy estimates over 5 million tons of dolomite at Sulai, but the varieties which crop out in the bed of the Mahanadi, south of Padampur, and others near Putka are siliceous. The red, white and mottled dolomites of Cuddapah age which form isolated hills near Kondajodi, in Koraput, are also of a siliceous character, but a purer grey kind extends for about a mile along the Kolab valley from Sirivada.

As far as is known at present Bihar's dolomite resources are meagre, though dolomitic limestones occur at Putada, near Chaibasa, in Singhbhum; at the top of the Rohtas Stage near Banjari, in Shahabad, and at various places in the Palamau district. In Bengal, a high range of hills in the western Duars is said to be built entirely of dolomites, members of the Buxa Series. Their rugged, precipitous cliffs, intercepted by steep-sided gorges, cover about five square miles in the north-eastern corner of Jalpaiguri district and extend onwards into Bhutan. D. K. Chandra states that fifteen representative samples had a magnesia content of over 21 per cent while the reserves are practically inexhaustible.

The 'Marble Rocks' of the Narmada gorge, Jabalpur district, Madhya Pradesh, are dolomitic, as also are various marbles known in the Betul, Chhindwara, Nagpur and Seoni districts: there are quarries in such occurrences at Khorari in Nagpur, and at Bhedaghat, Gwari and Rupaund in Jabalpur. Extensive beds of flux-grade stone are known to extend to the north and east of Kodwa, in the Drug district, where P. K. Chatterjee has computed that some 25 million tons are available. At Baraduar and other locations near Akaltara and Jairamnagar, in the Bilaspur district, dolomites are quarried for use in the iron and steel industries, while further occurrences have been noted in the Warora area of Chanda, and from Gowari Hill in the Wun *tahsil* of the Yeotmal district of Berar. Over the eleven years 1940 to 1950, inclusive, 91,834 tons of dolomite have been quarried at Baraduar, where production now averages about 20,000 tons per annum, with a further 2,000 tons yearly from Jairamnagar. Vindhya Pradesh possesses dolomite resources near Japi and other places not far from Umaria, in Rewa, while the crystalline limestones of northern Rewa, such as those of Ekprie and Perarwa, are highly dolomitic as a rule. Dolomitic marbles are also known to exist in the Dhar district of Madhya Bharat, while in Hyderabad, the Pakhal Series of the Warangal and Asifabad districts contains several bands of the same character.

The well-known Rajnagar marble, which covers wide areas in Mewar, Rajasthan, is a dolomitic stone, as indeed are a number of other white marbles reported by B. C. Gupta from the same region. The equally well-known Raialo Marble of Jaipur and Alwar approximates closely to a true dolomite in its composition, while the so-called Ajabgarh Limestone of Tonkra, in Kishangarh,

is, in reality, a coarsely crystalline dolomite. The marbles of Banswara, and their northern continuations in the Jhari reserved forest of Dungarpur, are also believed to be dolomitic. In Bombay, the Matipura marble of Baroda is a siliceous dolomitic limestone with 17 per cent of magnesia and 34 per cent of lime. Occurrences of dolomitic marble of no great extent have been found by P. N. Mukerjee at Wannar and Deohati in Chhota Udaipur, but near the northern boundary of Jambughoda about three million tons are probably available. On the slopes of the Western Ghats, south of the Deccan Trap region, there is a great deal of dolomite, as, for instance, in the great massif crowned by the old Mahratta fort of Bhingarh, east of Goa.

The Vempalle Limestone of the Lower Cuddapah rocks of Andhra is essentially a siliceous dolomite of wide extent, for its outcrop has a breadth of from one to four miles and extends from near Cuddapah itself, through Rayalacheruvu, in Anantapur, to beyond Betamcherla, in Kurnool. Many of the crystalline limestones of Archaean age in south India, like their counterparts in the Archaean rocks further north, are dolomitic in composition, and such occurrences have been reported from Salem, Visakhapatnam and other districts. They are also abundant in the Shimoga, Tumkur and Chitaldrug districts of Mysore in any quantities which may be required. Supplies for the Mysore Iron & Steel Works come from quarries at Shankargudda, in the Shimoga district, and this stone is an interesting one in that it contains $1\frac{1}{2}$ per cent of manganese oxide, MnO . It is not uncommon for part of the magnesium in dolomite to be partially replaced by iron, with the formation of the mineral ankerite, $CaCO_3(Mg,Fe)CO_3$, a closely related species and intermediate between it and siderite, the carbonate of iron, $FeCO_3$; it is rarer but by no means unknown for manganese to take part in the same replacement. For the fifteen years ending 1950, a total of 27,707 tons of dolomite have been produced in Mysore for use as a flux in the Mysore Iron & Steel Works.

Dolomites and dolomitic limestones are of frequent occurrence throughout the whole length of the Himalayas, from Kashmir in the west to the Dihang valley in the extreme east, though only the more important of them can be referred to here. The bulk of the Great Limestone of Jammu and Kashmir consists of siliceous dolomites but they average over 6 per cent of impurities according to J. B. Auden. Massive dolomites occur in the Beas valley of Kulu, while the dolomites of the Upper Krol Series appear in Mandi in Himachal Pradesh. Further south, in the Sutlej valley of Suket (south of Simla), the massive grey dolomitic limestones of the Shali Series are believed to be of much the same Permo-Triassic age. In their type section at Krol, near Solon on the Kalka-Simla road, whence they extend south-east well

into Sirmur, the strongly bedded, dense, closely sub-crystalline, blue dolomites of the Upper Krol Series are 600 to 800 feet thick. The same rocks continue into the Chakrata area of the Dehra Dun district of Uttar Pradesh, and are found again near Narenchnagar, in Tehri Garhwal, thence, after a gap of some extent, they are known again in the Mussoorie area of Naini Tal district of Uttar Pradesh. Hereabouts, the pale, almost porcelainous dolomites are remarkable for their low content of silica and other impurities, rivalling, in this respect, the best qualities from Birmitrapur, in Sundargarh, Orissa. In Tehri Garhwal there is another series of massive dolomites, though they are often siliceous, stretching as part of the Deoban and Garhwal Window Series through Gangani and Pratapnagar, to the south-east, past Kaproli and into the Garhwal district. They often show signs of mineralization, becoming sideritic at Uttarkashi and elsewhere and carrying diffused impregnations of copper ores at Kaproli, Pokhri and Dhanpur. In the same way, the siliceous dolomites of the same age and constitution which occur in eastern Kumaun bear indications of an iron-copper mineralization while, as V. P. Sondhi and S. P. Nautiyal have demonstrated, the eastern outcrops are sometimes extensively replaced by magnesite. Such dolomites are known in Sallyana in western Nepal.

The dolomites of the Outer Himalayan ranges lying within Indian territory may be expected again in the Himalayan parts of the West Punjab and the North-West Frontier Province of Pakistan. Both dolomite and dolomitic limestones are associated with the gypsum deposits of the Salt Range, usually as flaggy bands up to several feet in thickness but liable to die out when traced laterally. In the extreme eastern part of the Range, on the southern side of the Bunhar river, just north of Waghh, E. R. Gee states that much thicker, massive, light-coloured dolomite caps the Saline Series. The massive Kioto Limestones of the Potwar, which may be of Lower Jurassic or Upper Triassic age, are often high in magnesia content, as also are some of the Productus Limestone bands which form crags on the outer escarpments of the Salt Range. The so-called 'Magnesian Sandstones', of the Salt Range Cambrian, are better described as sandy dolomites and indeed are represented by a group of dolomites in the Khisor Range further to the west and across the Indus. From the North-West Frontier Province, A. L. Coulson has reported dolomites in the Kurram Agency and grey and greyish-white, saccharoidal varieties from the Ghundai Tarako Hills on the boundary between the Mardan district and the Buner tract of Swat.

Dolomites and dolomitic limestones occupy vast areas in the Shan States of Burma and are responsible for the distinctive characters which the upland plateaus of these regions have assumed—monotonous successions of wide shallow valleys, separated

by low, swelling ridges, smoothed by the universal covering of red clay into which the rock weathers down, and only broken by cliff-like fault scarps or by deep canyons which the major rivers have excavated in the soluble stone. Careful computations have shown thicknesses varying from 3,000 to 6,000 feet for this single formation in different places, and it is to be noted that, although dolomitic limestones with from 19 to 33 per cent of magnesium carbonate are common, much of the rock, and probably its greater bulk, contains the two carbonates in the proportion demanded of a true dolomite. It is a whitish or light grey rock, of a finely granular appearance, composed of aggregates of minute, interlocking dolomite crystals, often traversed by veinlets of secondary calcite.

ANALYSES OF INDIAN DOLOMITES

DISTRICT	LOCALITY	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Loss on Ignition	REMARKS
Jalpaiguri	Sachaphu ..	1.76	0.48	0.76	29.63	21.07	46.41	Baxa Stone. Mean of 16 analyses
Sundargarh (Gangpur)	Birmitrapur	2.95	1.30	0.80	30.58	19.55	44.35	Bisra Stone & Lime Co.
—do—	Panposh ..	1.30	0.45	0.65	30.20	21.15	46.03	Tata I. & S. Co.
—do—	Amghat ..	3.06	1.15	..	29.99	20.37	44.94	G.S.I.
Sambalpur	Sulai ..	3.40	0.02	0.78	29.68	20.41	45.46	G.S.I.
Bilaspur	Akaltara ..	4.03	1.12	1.20	30.22	18.91	44.13	Cuddapah Stone. Mean of 22 samples
Yeotmal	Gowari Hill	1.57	0.21	0.79	30.01	20.94	46.50	G.S.I.
Shimoga	Shankar-gudda	2.60	4.00	1.55*	32.01	16.72	43.17	Mysore I. & S. W.
Jodhpur	Bilara ..	0.44	0.32	0.26	31.02	20.72	..	Jodhpur State
Mewar	Rajnagar ..	..	..	..	32.67	21.09	41.09	Rainla Stone
Chhota Udaipur	Deohati ..	1.38	0.52	..	30.03	21.22	46.58	G.S.I.
Dehra Dun	Mussoorie ..	0.20	1.62	..	29.95	20.82	46.72	Up. Krol Stone. Mean of 6 samples
Garhwal	Gohna ..	1.36	1.23	..	30.17	21.41	..	G.S.I.

* MnO

Note.—Jalpaiguri is in West Bengal. Gangpur and Sambalpur are in Orissa. Bilaspur and Yeotmal are in Madhya Pradesh. Shimoga is in Mysore. Jodhpur and Mewar are in Rajasthan. Chhota Udaipur is in Bombay. Dehra Dun and Garhwal are in Uttar Pradesh.

ANALYSES OF DOLOMITES FROM PAKISTAN AND BURMA

DISTRICT	LOCALITY	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Loss	REMARKS
Jhelum-	Waghh ..	0.06	0.22		31.43	31.02	47.75	Saline Series. Top
-do-	Nilawan ..	3.92	3.00		26.71	19.72	45.10	-do- Gypsum Stage.
Mianwali	Buri Khel ..	0.26	7.36		31.05	16.80	45.00	Basal Jurassic
Jhelum	Basharat ..	2.97	3.17		29.56	19.41	44.90	Magnesian Sand-
								stone Series
D. I. Khan	Kingriali ..	0.88	1.66		31.05	20.11	46.24	Basal Jurassic
Buner	Ghundai ..	0.24	0.40		31.58	20.98	46.36	Grey dolomite
	Tarako							
	(S.E. end)							
Mardan	-do-	0.60	0.70		32.27	19.92	46.21	-do-
	(S.W. end)							
Mandalay	Zebingyi ..	0.35	0.49		31.90	20.38	..	Plateau Limestone
-do-	Baw ..	3.43	2.11		34.01	15.90	..	-do- with calcite
								cracks
Hsipaw	Yebin ..	1.87	0.63		30.29	20.47	..	Plateau Limestone
North	Mongyaw ..	0.01	0.87		31.73	20.21	..	-do-
Hsenwi								

Notes.—The Jhelum and Mianwali districts are in the West Punjab and the localities mentioned are in the Salt Range.

Dera Ismail Khan and Mardan are districts in the North-West Frontier Province. Buner is a tract of Swat in the same Province.

Mandalay is a district of Upper Burma.

Hsipaw and North Hsenwi are States of the Northern Shan States.

MAGNESITE

There are three commercial varieties of magnesite, the carbonate of magnesium, $MgCO_3$, the most important of all the basic refractory minerals: they are the compact or cryptocrystalline, to which the south Indian occurrences belong; the spathic or coarsely crystalline, examples of which have been described by V. P. Sondhi from Dewal Thal, Almora district, Uttar Pradesh and by S. P. Nautiyal from the same district; and another crystalline kind known as breunnerite, which contains over 5 per cent of isomorphous carbonate of iron and has been found near Dev Mori, Idar, Bombay and adjoining tracts of Dungarpur, Rajasthan. The magnesite of south India, a hard, white, brittle mineral resembling unglazed porcelain, is the only one of economic interest at the present time.

Dr Heyne is said to have discovered the great magnesite deposits of the Chalk Hills, in the Salem district of Madras, in the early years of the nineteenth century and by 1825 official interest had been aroused in them, but it was not until about 1900 that actual development began with the formation of the Magnesite Syndicate by H. G. Turner. The first production returns appeared in 1902 and the same Syndicate has continued its operations up to the present time.



A MAGNESITE QUARRY IN THE CHALK HILLS, MADRAS

The plains surrounding the Chalk Hills are occupied by biotite gneisses and charnockites; the hills themselves are essentially two great intrusive masses of ultrabasic rocks (dunites), in which the magnesite occurs as an intricate network of irregular veins. Some of these are over three feet thick, but the general average is only a few inches, while together they form 6 to 10 per cent of the whole mass, distributed in richer or poorer patches. There are two areas, separated by a tongue of crystalline rocks, of 4.4 and 1.1 square miles containing reserves of $82\frac{1}{2}$ million tons, to an assumed depth of 100 feet only. Petrological studies have shown that the Salem magnesite, which averages 96 to 97 per cent of magnesium carbonate, was formed under conditions of high temperature and pressure; the processes involved were not superficial ones as is often the case elsewhere, and it follows that the deposits probably continue to considerable depths.

Several other occurrences are known, not only in Salem, but also in Tiruchirapalli (Trichinopoly), Kurnool, Bellary and Coorg, though they are insignificant in comparison with the vast resources of the Chalk Hills. At Dod Kanya and Dod Katur, in the Mysore and Hassan districts of Mysore, however, there are magnesite veins of a commoner type, in serpentine derived from the hydration of the olivine of the original ultrabasic rocks (mainly dunites), which have been quarried by Tata Industries Ltd at Dod Kanya, about 12 miles from Mysore City, since 1921. Other occurrences worthy of mention include those north-west of Bhitari, in Singhbhum, where magnesite is accompanied by talc, and the veins which traverse serpentines to the north of Bania Pani, south of Wad, in Jhalawan, eastern Baluchistan. According to E. W. Vredenburg, 'magnesite thus situated and in such abundance, might be worth extracting in the event of a railway extension to Las Bela'. A large deposit of magnesite has been located recently by S. P. Nautiyal near Gree Chhina, Almora district, Uttar Pradesh.

Magnesite is the source of magnesia, the oxide of magnesium, MgO , of which there are two leading industrial varieties. When the mineral is roasted in a kiln at temperatures of 1000° to 1200° C. a product is obtained which still contains two or three per cent of carbon dioxide and which is capable of absorbing moisture and carbon dioxide from the air. This is known as Caustic Magnesia; mixed with strong solutions of magnesium chloride it is the chief component of the Oxychloride or Sorel cements. These materials set as hard, tough, resilient compositions and, being durable, dustproof and fireproof, are esteemed as floorings in public buildings, hospitals, laundries, ships, railway coaches and factories, especially those in which inflammable and explosive substances are made or handled. They are also used for fireproof partitions, tiles and artificial stone as well as for bonding abrasives in grindstones, milling stones, cutting wheels and so

forth. Caustic magnesia also finds applications in stucco-work, mouldings, plasters, wall boards and insulating materials and it is a valued accelerator in the processing of rubber.

When the calcining is carried out at higher temperatures, in the 1500° - 1600° C. range, the product contains less than one half per cent of carbon dioxide and consists mainly of periclase, MgO , a very stable, inert, resistant form of magnesia. This is the 'dead-burnt' or 'sintered' magnesia which is made into refractory bricks for lining basic, open-hearth steel furnaces; copper and lead smelting and refining furnaces; melting furnaces for aluminium and copper alloys; cement kilns; chemical furnaces; in fact in any situation where a basic lining capable of withstanding high temperatures is required. In steel works it is often used in the form of granules ('peas') which, mixed with ground dolomite, are rammed into the furnace bottom as a kind of concrete to form the hearth. The greater part of the magnesite produced in the world is used in this dead-burnt condition. Pure magnesia, heated to about 2500° C. in the electric furnace, fuses into an extremely durable, white, crystalline form, a refractory substance unusually able to withstand the chemical action of molten metals, basic slags and fluxes at high temperatures. It is made into a variety of shapes and commonly used for immersion heaters, resistance elements, melting-pots, annealing chambers and laboratory wares. South Indian magnesite is peculiarly well adapted for the manufacture of fused magnesia and has been employed for this purpose in both Norway and England. Its performance on an experimental scale in Indian steel works has been excellent, but its high cost prohibits its general use. Magnesia is also an important heat-insulating material and mixtures of it with asbestos, with a guaranteed magnesia content of 85 per cent, have been made at the Himatnagar works of the Pioneer Magnesia Co. for many years, the total production between 1938-9 and 1949-50 being 1,032 tons. In this case, however, the magnesium compounds are derived from the bitterns of the Khara-goda brines. Magnesite and magnesia are used in the composition of some varieties of porcelain table-ware, as well as in low-loss insulators for the radio industry. Magnesium orthotitanates, made by firing mixtures of magnesia and calcined rutile, often with the addition of zirconia, are reported to be ideal dielectrics for condensers. Other uses of magnesite are described under MAGNESIUM.

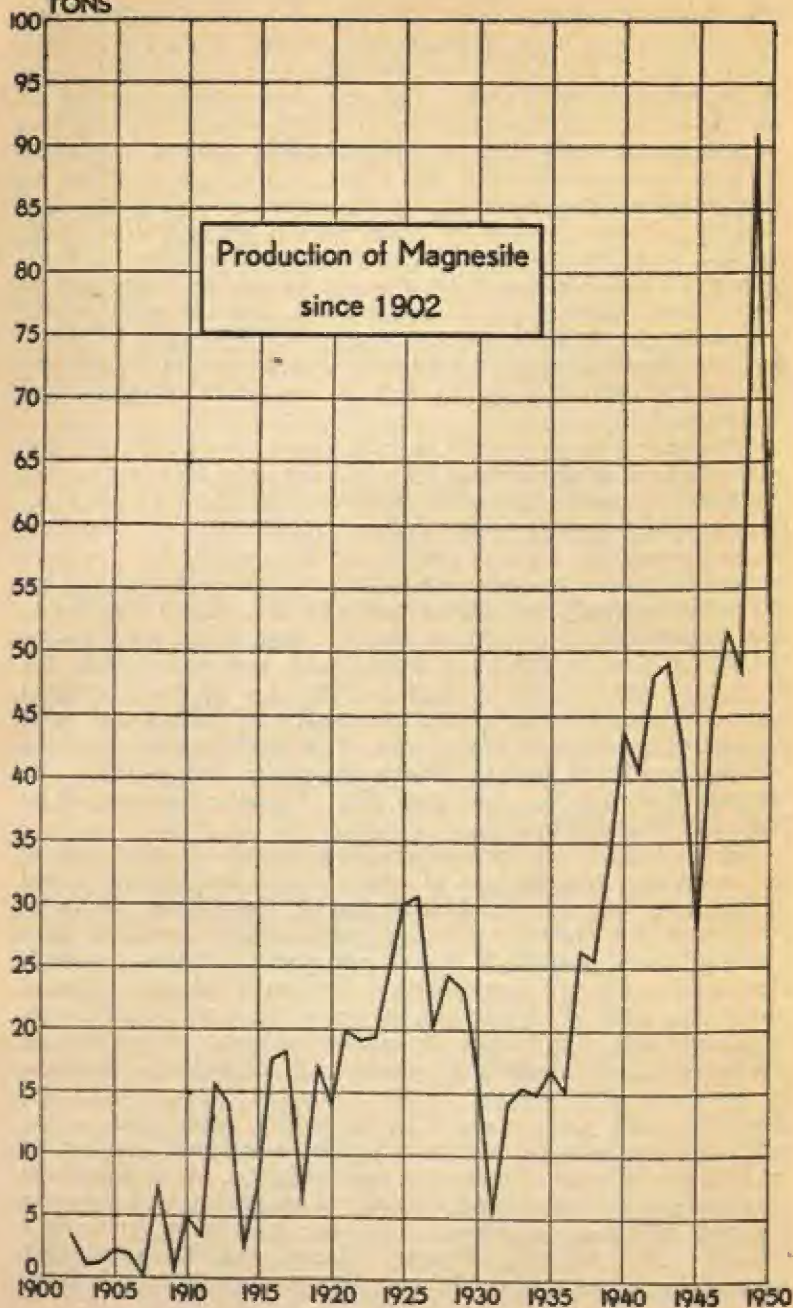
The bulk of the magnesite produced from the Salem deposits is exported through Madras and Cochin, but considerable quantities of both caustic and dead-burnt magnesia are also made on the spot. The principal users in India are the Tata Iron & Steel Co. Ltd, who consume annually about 5,000 tons, divided equally between magnesia bricks and granules ('peas'). There are two manufacturers of such products, the firm just named

with its works at Jamshedpur, and Burn & Co. Ltd at Raniganj. Both obtain their raw material from Madras and Mysore, and there is little difference in its composition in either case. Both plants are of modern design and meet the requirements of all the Indian steel-making companies in bricks, granules and cements for fettling purposes. The practice of using unburnt magnesite bricks in cement kilns, the first firing of which is supposed to bake the brick to a requisite degree, has not proved economical in Indian works. Magnesite bricks have a tendency to splinter (spall) under thermal shock caused by rapid changes of temperature, but this can be largely overcome and the refractoriness under load increased by using suitable graded mixtures of magnesite and chromite, and such bricks are now made in India. Some modern varieties of chrome-magnesite bricks contain 70 per cent of chromite grains and 30 per cent of dead-burnt magnesite.

From the commencement in 1902 up to the end of 1950 the total output of magnesite was 1,219,764 tons, and for this quantity the Salem deposits alone were responsible for about 92 per cent, the remainder coming from Mysore. For the five years ending 1948, the average annual production was 42,963 tons, valued at Rs 5,85,340, compared with 42,885 tons and Rs 3,26,958 for the period 1939-43, and 19,841 tons and Rs 1,26,051 for 1934-8. The highest recorded output was in 1949, when 90,564 tons valued at Rs 15,53,456 were raised. In 1950, production fell to 52,859 tons, valued at Rs 11,60,687. On an average taken over a number of years about one quarter of India's magnesite production has been exported, and other producers besides those already mentioned include Salem Magnesite Ltd, which commenced operations in 1940, and The Magnesite Corporation of India Ltd, founded in 1945.

The world's production of crude magnesite in 1937 was of the order of 2,100,000 tons of which the Soviet Union yielded 37 per cent, Austria 21, Manchuria 15, the United States of America 8 and Greece 7 per cent, with smaller quantities from Czechoslovakia, Yugoslavia, Korea and India. For later periods complete figures are unobtainable, but in 1948 the Austrian production totalled almost 395,000 tons and the United States of America's 324,355 tons of the calcined mineral. India headed the list of Commonwealth producers with 48,327 tons, followed by Australia with 32,442, South Africa 10,492, and Southern Rhodesia with 5,632 tons. The Canadian production is not taken into account because it is mainly a calcined product of an intimate mixture of magnesite and dolomite. It is thus clear that there is no widespread shortage of magnesite and that the exported Indian mineral meets strong competition in the world's markets. The Austrian, Russian, Manchurian, Canadian and some of the American deposits are of the crystalline, spathic type,

THOUSAND
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resulting from the replacement of limestone or dolomite by ascending solutions of magnesian salts. The Austrian mineral, which for many years dominated the markets of the world for dead-burnt magnesia, is a variety of breunnerite.

Indian magnesite, on the other hand, is of the compact, crypto-crystalline type, similar to the Grecian supplies which have always been its chief competitor. The Grecian deposits, lying on the Aegean coasts of Euboea, enjoy the advantage of cheap sea freights to the consuming centres, whereas the Indian product is handicapped both by the railway freights to ports 200 miles away, and the longer sea voyages to the principal markets in America and Europe. The high quality of the Indian mineral is its principal recommendation abroad and this should never be imperilled by the shipment of inferior grades. The Indian demand will expand with the growth of the steel industry, with the more extended use of the oxychloride cements, and, if cheap electric power becomes available, with the production of fused magnesia goods for both home and foreign consumption.

SILICA

The uses of quartz (silica) in the ceramic industry and particularly in the manufacture of chinaware and porcelain have been considered on another page, and here we are only concerned with its applications as a refractory material.

Good-quality siliceous sand, rammed into place, may be used in the hearths of some types of metallurgical furnaces. Thus, a sand consisting almost entirely of pure silica, from the Jabalpur district of Madhya Pradesh, has been employed by the Tata Iron & Steel Co. in making the bottoms of its acid steel furnaces. For the linings of acid Bessemer converters at the same steel works, quartz schists, quartz granulites and quartzites, the practical equivalents of the English gannister, are used. The main sources of supply are in the Singhbhum district of Bihar, where the Tata concern has opened quarries between Rakha and Kendadih. One, under active exploitation at the present time, is situated on Kandey Dungri hill, 3 miles from Sini on the main line of the Bengal-Nagpur section of the Eastern Railway.

Silica bricks are used in roofing open-hearth steel furnaces where temperatures of 1650° C. may be reached, in metallurgical furnaces of other descriptions, in gas-making plants, in electric furnaces, coke ovens, glass works and ordnance factories. They cannot be utilized for ordinary refractory purposes as they disintegrate under rapid changes of temperature. There are two factories on the Raniganj coalfield where silica bricks are made—the Kumardhubi Fireclay and Silica Works of Bird & Co. Ltd, founded in 1915, and the Lal Koti Works of Burn & Co., which

commenced in 1918. The raw materials used in both cases are unusually pure quartzites from the Rajgir Hills of the Gaya district, from the Kharakpur Hills and Ratanpur of Monghyr and from Biharsharif in Patna district. After crushing the rock to a suitable powder, a slurry made up of water with 2 per cent of lime is mixed with it. This makes the material slightly plastic and it can then be moulded into bricks or any desired shapes. The Kumardhubi works can mould 9,600 regular bricks and 30 tons of shapes daily, though this includes a certain proportion of sillimanite products which are also made here. In the firing section of the same works there are 13 round, down-draught kilns with a capacity of 240 tons, or 67,000 regular bricks. It may be added that another department of the same works can mould 20,000 firebricks and 23 tons of fireclay shapes per day, while to burn these there are eight round, down-draught kilns with a capacity of 92 tons, or 23,000 regular bricks each; one rectangular kiln with a capacity of 55 tons, or 13,700 regular bricks, and one tunnel kiln with a capacity of 1,200 tons, or 300,000 regular bricks per month. In addition, there is an oil-fired rotary kiln which is used for the calcination of kyanite, bauxite and fireclays, with an average monthly output of approximately 665 tons. At the Lal Koti works there are 10 kilns capable of producing about 1,000 tons of silica bricks per month.

The burning or firing of silica bricks is a long, difficult and expensive process. In the moulded stage they are fragile and need careful handling and elaborate drying arrangements. After this, the loading of a normal kiln takes about 3 days, and in the setting the whole of the bricks and shapes are covered with already burnt material to prevent the flames of the fire from shattering them. Slow firing in the early stages drives off the moisture; as the temperature increases the lime which was added as a slurry, as well as the iron and any basic impurities in the quartzite, fuse and form a solid mass binding the quartz particles together to make a solid brick. During the final stages of the burning the quartz changes into cristobalite or tridymite, and at 1500° C., the volume increases by about 5 per cent and the brick expands in all directions. The temperature in the kiln is maintained at this figure for about 24 hours, and the whole of the firing period thus described, more or less in the words of W. H. Bates, the General Manager of Burn & Co.'s potteries, takes 12 days. Cooling too must be most carefully regulated and spread over a period of 10 to 12 days. 'Storage demands large rain-proof sheds, because if they are exposed to the rain or climate, the bricks lose their freshness and are of no use.'

From Orissa extensive deposits of pure quartzite, suitable for refractory purposes, have been described as occurring in the Khajuria-Pravasoni region of Bamra, and in the easily accessible ridges of Baigharra, Jharghati and Garpati, in Sambalpur.

Large quantities of friable quartzite with a silica content of 98 per cent and very little iron are said to be available in the Dodguni area of the Tumkur district, Mysore.

Indian silica bricks are made to standard specifications and in the crucial tests of actual use they have proved equal to those of any other country. No foreign materials of this type have been imported for many years and the industry is quite capable of meeting any future demands which may arise. At the present time its productive capacity exceeds the internal demand.

ANALYSES OF QUARTZITES USED FOR SILICA BRICKS

LOCALITY	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Alks.	Loss	TOTAL
Gaya District ..	97.15	0.76	0.91	0.10	0.01	0.08	0.20	99.21
Kiul, E. Rly. ..	98.67	0.48	0.41	nil	0.06	0.06	0.80	100.48
Barakar, —do— ..	96.26	1.60	1.40	0.60	tr.	tr.	..	99.86
Monghyr District..	96.86	1.26	0.14	0.38	0.14	0.13	..	99.91

ANALYSES OF INDIAN SILICA REFRACTORIES

MAKER	BRAND	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Alks.	TiO ₂	Loss	TOTAL
Kumar-dhubi	Bird's ..	94.90	1.34	0.44	2.12	0.11	0.72	..	0.08	99.71
Burn & Co.	Lisil ..	94.80	1.24	1.10	2.50	..	..	1.00	..	100.64
—do—	Claysil ..	94.50	3.96	0.62	0.10	0.40	0.18	0.25	..	100.01

Note.—The analyses in both these tables have already been quoted by W. H. Bates.

'Claysil' is a name given to a speciality product in which small amounts of clay have been used as a bond replacing the more usual lime. Such bricks have been largely used by the Indian Iron & Steel Co. Ltd and others for coke oven linings.

CHROMITE

In addition to its uses already described under CHROMIUM, chromite is a valuable refractory material, an application which is important enough to account for some 40 per cent of the world's annual consumption of the mineral at the present time. It is often described as a neutral refractory material and it is employed in steel furnaces, as a layer between the basic hearths and the acid (siliceous) roofs, which if heated in contact with one another are likely to fuse owing to the formation of fusible silicates. Bricks made from chromite are not harmed either by contact with magnesian (basic) bricks or acid (silica) ones. Moreover, chrome bricks when properly made should only commence to soften between about 1850° and 2000° C. Of late years linings of chrome-magnesite bricks have been increasingly adopted for the hearths, ends and back and front walls of steel furnaces, and

the tendency appears to be to extend their use to the roofs as well, developments for which their stability, neutrality and resistance to spalling are largely responsible. In German practice, roof lives of steel furnaces extending over 1,000 to 1,400 heats have been quoted for chrome-magnesite bricks, compared with about 400 heats from silica bricks under similar operating conditions. The use of chrome and chrome-magnesite bricks is not confined to the steel industry and they are used in many other types of metallurgical furnaces where neutral linings are necessary.

The modern British brick of this type generally contains about 70 per cent of chromite grains (coarse and medium) and 30 per cent of calcined magnesite in the finer fraction. It has been stated that the most suitable chrome ore for the chrome-magnesite bricks for a steel furnace roof should contain less than 18 per cent of iron oxide (FeO) and between 3 and 6 per cent of silica (SiO_2). The manufacturing processes are much the same as those adopted in the case of magnesite bricks, and the same high temperatures are necessary to produce a suitable article. Chromite bricks are manufactured in India by the Tata Iron & Steel Co. Ltd, by Burn and Co. Ltd, and by the Kumardhubi Fireclay and Silica Works Ltd. The annual production of about 2,600 tons is sufficient to cope with present requirements and can be expanded when the need arises.

In addition to the deposits mentioned under CHROMIUM, more recent finds of chromite have been reported from areas close to Nausahi and also from the adjoining Sukinda Estate in the Cuttack district and in Dhenkanal, Orissa. Chromite has also been discovered in association with other minerals, as parallel bands in the anorthite gneiss, 11 miles south of Tiruchengodu, in the Salem district of Madras. These ore-bearing bands have been traced over a distance of 12 miles, and the mineral is said to be amenable to concentration by magnetic methods into products suitable for refractory purposes.

Indian chrome refractories are at present made from Singhbhum ores, and the Panel on Ceramics and Refractories, reporting in 1948, after a warning that India's reserves of chrome ores, in comparison with those of Pakistan, are not high, added the following remarks: 'The Singhbhum chromite deposits which are

COMPOSITION OF INDIAN CHROME-MAGNESIA BRICKS

MAKER	BRAND	Cr_2O_3	MgO	CaO	Fe_2O_3	Al_2O_3	SiO_2	TOTAL	FUSES AT
Burn & Co.	Chromo	44.18	9.60	..	25.58	16.08	4.13	99.57	2000° C
Tata Iron & Steel Co.	1st	.. 15.10	49.37	2.00	10.86	5.74	17.56	100.63	..
—do—	2nd	.. 34.40	29.39	2.10	18.29	9.31	6.60	100.09	..

TONS

65

60

55

50

45

40

35

30

25

20

15

10

5

0

1905

1910

1915

1920

1925

1930

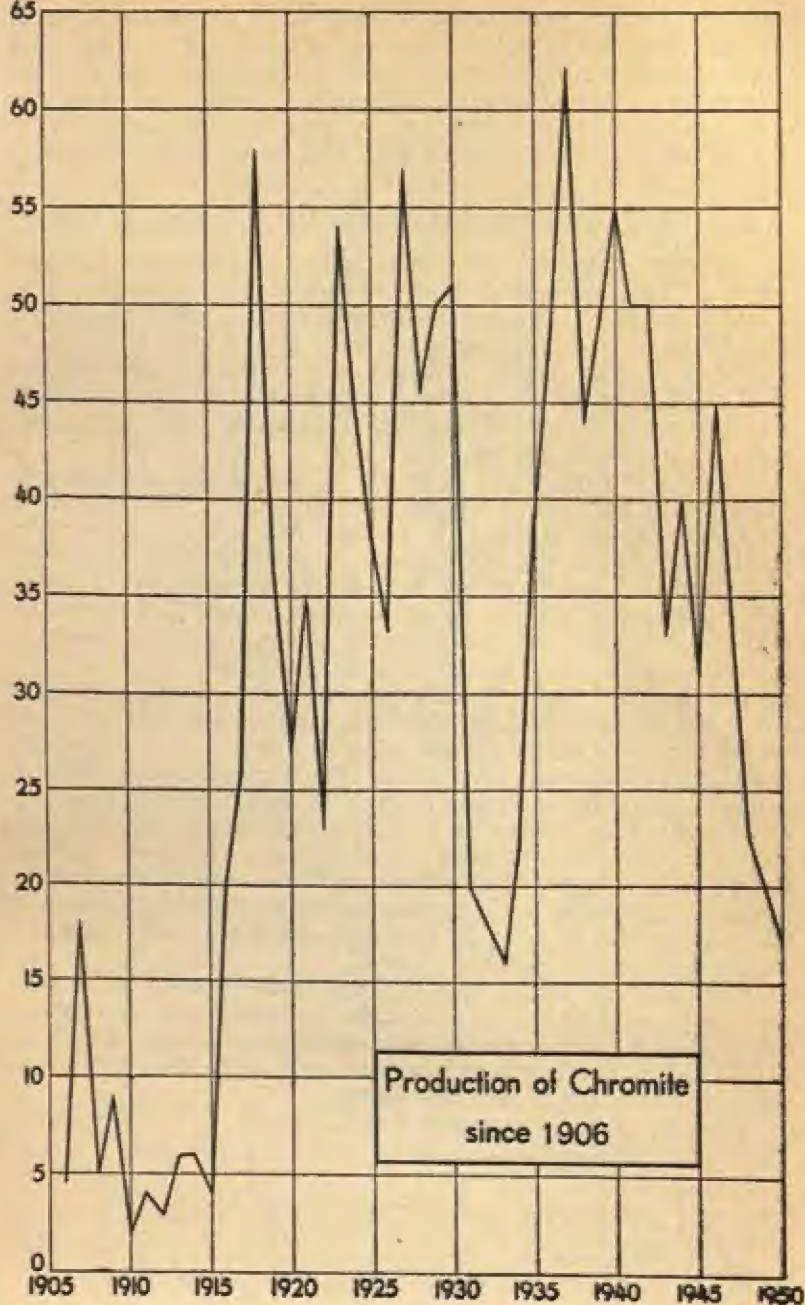
1935

1940

1945

1950

Production of Chromite
since 1906



used for making refractories, are mined by a number of small holders, who use crude and wasteful mining methods, with the result that there is danger of permanently damaging these deposits. We believe that a systematic national policy regarding these and other raw materials is necessary to prevent their depletion by injudicious and uncontrolled export and crude mining methods.'

BAUXITE AND THE ALUMINOUS REFRACTORIES

Although bauxite is sometimes added to fireclays to increase their alumina content and the refractoriness of the firebricks made from them, the term 'aluminous refractories' should be limited to those containing more than 45 per cent of alumina, and is correctly applied to bauxite bricks with an alumina content of from 45 to 80 per cent of alumina, or to the mullite refractories made from kyanite, sillimanite and andalusite, descriptions of which follow.

Bauxite is a rarer and more costly mineral than fireclay and often has to bear heavy freight charges to the works where it is used; furthermore, it has to be calcined before being mixed with the fireclay which supplies the necessary plasticity for moulding, and there is a loss of 27 per cent during the calcination process. While fireclay goods are burnt at temperatures between 1200° and 1400° C., bauxite bricks require a temperature of 1500° C. if a sufficiently strong brick is to be produced; it is not surprising therefore that they are expensive and used only in special situations where unusually high temperatures are met with, as in the linings of rotary cement kilns, or, again, in others where resistance to basic slags is required. Registered brands of bauxite bricks made in India contain from 60 to 80 per cent of alumina, and compare favourably in both composition and performance with the best of foreign products of the same type. W. Gilbert states that in a 60 per cent Indian-made bauxite brick, the mullite content is about 80 per cent, the melting-point over 1760° C., whilst under a load of 25 lb. to the square inch it will withstand temperatures in the region of 1600° C.

Aluminous refractory concretes are made by mixing bauxite cements ('*ciment fondu*') with suitable aggregates, such as crushed firebrick, and have extremely wide applications in such situations as flue and chimney linings, kiln floors and walls, furnace foundations, coke oven arches and door linings.

The uses of pure alumina as a refractory are considered under THE OXIDE REFRACTORIES (p. 425).

SILLIMANITE, KYANITE AND ANDALUSITE

The minerals sillimanite, kyanite and andalusite are all silicates of aluminium possessing the same chemical composition,

$\text{Al}_2\text{O}_3 \cdot \text{SiO}_2$, and made up of 63.2 per cent of alumina with 36.8 per cent of silica, but differing in their physical properties. When heated to 1545°C. , all three minerals change into mullite, another aluminium silicate with the formula $3\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2$, containing 71.8 per cent of alumina and 28.2 per cent of silica, which is itself stable up to a temperature of 1810°C. For most refractory purposes, good fireclays such as those whose composition has already been described are adequate raw materials, for they too on strong heating form mullite, though it is more or less contaminated with silica in the form of cristobalite. When the finished refractory articles, however, have to endure unusually high temperatures, or the attack of corrosive melts and fluxes, conditions under which normal fireclay products break down, raw materials containing more silica or more alumina are called for. The uses and the limitations of silica bricks are described on another page: the minerals to be dealt with now belong to a group known as the 'high alumina refractories'.

Kyanite is the commonest mineral of the three but its conversion into mullite involves an increase in volume of about 18 per cent, at temperatures over 1350°C. It has, therefore, to be calcined before use, though the shattering which it then undergoes eases its later crushing for manufacturing purposes. Products derived from calcined kyanite are often referred to as 'sillimanite' in the trade. Mullite has many properties of value in the ceramic industry, and porcelain made from it possesses stability at high temperatures, good mechanical strength, a low coefficient of expansion and a high electrical resistance. It is not a plastic mineral and must be mixed with clay to make it workable, before being shaped by any of the usual methods, tamping, pressing, extrusion, casting or jollying and turning, depending on the size and configuration of the article required. Ordinary sillimanite ware contains between 40 per cent and 66 per cent of sillimanite and 60 per cent to 34 per cent of fireclay. Special quality sillimanite ware may contain up to 95 per cent of sillimanite, and higher quantities still are said to be obtainable by mixing the sillimanite with silicon ester. Ordinary sillimanite ware is fired at temperatures of about 1500°C. to 1600°C. , the special wares at higher temperatures still, in furnaces lined with sillimanite bricks. Sillimanite wares have their applications in the manufacture of sparking plugs, pyrometer tubing, electrical and laboratory porcelain, saggars, and 'furniture' for the support of heavy pieces of china and porcelain in the kilns during firing. High-grade powdered kyanite is also used as an ingredient of low-alkali glass.

It is as a refractory, however, that mullite finds its widest usage, for in addition to its qualities already mentioned it has others peculiarly adapted for this purpose. They include its freedom from volume changes, its neutral reactions, its resistance

to thermal shock and spalling, as well as to the chemical attack of many gases, fluxing oxides and silicates, besides the abrasion caused by moving charges. It can carry heavy loads at high temperatures, possesses a moderately high thermal conductivity and is equally efficient in oxidizing or reducing atmospheres. It is not surprising, therefore, that it has proved eminently suitable, in the form of prefabricated bricks, blocks and shapes, for industrial furnaces of many kinds, including those for high-melting-point alloys, in which it is reported to have ten times the life of fireclay refractories; glass furnaces, tanks and pots and components used with them, such as burner blocks and tubes for feeding molten glass to the forming machines; combustion chambers; cement and pottery kiln linings; gas and oil fire-boxes; retorts, muffles, crucibles and small articles of many descriptions. A considerable proportion of kyanite refractories is used in electric induction and indirect arc furnaces for melting non-ferrous metals and their alloys, as for example in the refractory transformer slots of induction furnaces for the preparation of oxygen-free high-conductivity copper. Refractory linings of kyanite products in some types of copper refining furnaces are reported to have lives of at least one year, compared with lives of one to two months in the case of the refractories they have replaced in British practice. Mullite and other high-alumina refractories, however, are unsuitable for exposure to iron oxide slags. Cements, mortars and plastic ramming mixtures made from mullite are also on the market.

Another Indian mineral which may be used for refractory purposes is dumortierite, a borosilicate of aluminium, $\text{Al}_4\text{BSi}_2\text{O}_{11}(\text{OH})$, which contains 64.6 per cent of alumina, 28.5 per cent of silica, 5.5 per cent of boron trioxide and 1.4 per cent of water. It too decomposes into mullite at about 1250°C . Dumortierite is mined in Nevada in the U.S.A., mainly for use in the production of electrical porcelain for sparking plugs. Dumortierite, like sillimanite, can be used for some refractory purposes without previous calcination, by reason of its relatively small dimensional change on conversion to mullite. Topaz, the fluorine-bearing silicate of aluminium $\text{Al}_2\text{SiO}_4(\text{F},\text{OH})_2$, contains 55.44 per cent of alumina and like the minerals of the sillimanite group forms mullite when heated to a high temperature. When the supplies of Indian kyanite imported by the United States of America diminished during the last war, calcined topaz, or mixtures of domestic kyanite and topaz from South Carolina, were used as substitutes in the manufacture of refractories. Indian topaz rock, however, is more likely to be of value to India for its fluorine content of 20 per cent, particularly for making lead glazes and borosilicate glasses, and perhaps even as a substitute for metallurgical fluorspar in the steel and aluminium industries. It remains to mention that refractory bricks having approximately

the composition of mullite, and of other higher alumina to silica ratios, can be made by firing mixtures of suitable clays with calcined alumina minerals such as bauxite, $\text{Al}_2\text{O}_3 \cdot 2\text{H}_2\text{O}$, or diaspor, $\text{Al}_2\text{O}_3 \cdot \text{H}_2\text{O}$.

Sillimanite deposits of actual or potential commercial importance occur in India in Assam, Rewa, Bastar and Travancore. The sillimanite-corundum deposits of the Khasi plateau in Assam, of which twenty-one are known, lie almost entirely in the Nongstoin area, about the villages of Sona Pahar (Nongwawait), Nongpur and Nongbain. Most of them consist of massive sillimanite with a little corundum, one or two almost entirely of corundum and several of sillimanite alone. They are associated with cordierite-biotite-quartz-microcline gneiss and sillimanite-quartz schists and are intruded by granite. Impurities are not abundant and, according to V. P. Sondhi, a minimum quantity of 251,000 tons of sillimanite is available to a depth of 20 feet. Worked originally for corundum by the Khasi Mines Co., the presence of sillimanite was first detected in a consignment sent to London in 1921. Between 1916 and 1921, 6,645 tons valued at over Rs 2 lakhs were won, though the greater part of this was probably corundum. The inaccessibility of the region has prevented development, but in 1948, on the completion of a road, 23 miles in length, from Nongwawait to Haim at the foot of the plateau, operations were resumed by Messrs Pilkington Bros. Ltd, glass manufacturers. In 1951 a company, Assam Sillimanite Ltd, was registered, of which Steel Bros. & Co. Ltd are the managing agents.

Sillimanite occurs as boulders weighing up to 40 tons. The large boulders are blasted into fragments of which about a quarter is sufficiently large to be sawn into blocks of one cubic foot or more in size; the remainder is crushed and graded into three sizes, 1 inch mesh, 5×5 mesh to the inch, and 10×10 mesh to the inch down to flour suitable for direct use for making refractories and certain porcelain. The entire product is transported over 75 miles by road to Gauhati from where it is shipped by river steamer to Calcutta for marketing within the country and overseas. The large pieces are sawn into blocks at the sawing shed of Assam Sillimanite Ltd, at Paharpur in the Kidderpore dock, Calcutta. The plant, which commenced operations in September 1952, consists of two saws with diamond-impregnated phosphor bronze blades, motor-driven, rise and fall model with cross-traverse table. The blades are manufactured by Impregnated Diamond Products Ltd, Gloucester, England and consist of steel, 48" diameter and 0.299" thick; 68 phosphor bronze segments 1" wide by $\frac{3}{8}$ " thick are brazed on the rim. Each segment is $\frac{3}{8}$ " in depth and contains industrial diamonds sintered into the metal. The sillimanite blocks sawn are usually $18" \times 12" \times 8"$ size, equal to one cubic foot. They are suitable for refractory linings for glass tank furnaces

and the like and are said to have a useful life of two years or more for these purposes. The saw shed at Paharpur, Calcutta, has made a complete set of 740 blocks for a sheet glass tank under construction at Asansol for the Hindusthan-Pilkington Glass Works Ltd, a joint Indo-British concern. 'Experiments have shown that bonded blocks of crushed natural Khasi sillimanite can be made with as low as 16½ per cent apparent porosity by using a small proportion of "calgon" (sodium hexametaphosphate) in addition to a small quantity of clay. Excellent results have also been obtained by the use of polyvinyl alcohol as a bonding medium. It has also been demonstrated that artificial "sillimanite" or "mullite" refractories, manufactured with calcined kyanite as the principal ingredient, will show an increase in volume stability when a substantial portion of crushed natural Khasi sillimanite is added. The addition of natural Khasi sillimanite also enables a sharper mould to be made if this is desired. Bonded natural Khasi sillimanite blocks can be made capable of giving an excellent performance and can be produced to cope with a working temperature of 1650° C. Such bonded blocks are considered suitable for electrical arc-furnace or regenerator roofs of up to ten tons capacity, tapping with the roof temperature at 1750° C. Such blocks can be manufactured at less cost than the massive sawn blocks and can of course be moulded to any desired shape, including curves or tubes.' (Dunbar)

The corundum-sillimanite deposit of Pipra, Rewa, Vindhya Pradesh, is referred to under CORUNDUM. J. A. Dunn, taking an average depth of only 30 feet into consideration, estimated that about 100,000 tons of good material are available here, though owing to its intimate mixture with other minerals the possibility of recovering high-grade sillimanite is limited. The locality is 120 miles from a rail-head at Mirzapur, to which transport is by pack bullock. Minor deposits of sillimanite are associated with sillimanite-tourmaline rocks near Pohra, Bhandara district, Madhya Pradesh, and others are known near Keriapal, Samsatti and Chintaguppa in Bastar. The mineral has also been reported from Hsipaw, one of the Northern Shan States of Burma. In some countries both sillimanite and kyanite are recovered on a commercial scale from schists containing 10 to 15 per cent of the minerals. The abundant khondalites (sillimanite-quartz schists) of south India are a potential source of supply which may come to be drawn on in the future, as may rocks such as the quartzites of Bettabid, in Mysore, which contain radiating nests of sillimanite, up to one foot in diameter. Indeed, 23 tons of sillimanite were recovered in Mysore in 1950.

Sillimanite concentrates are recovered as by-products in the separation of ilmenite and monazite from the beach sands of Travancore. The zircon, rutile and sillimanite left after the removal of the other constituents are recovered in turn by gravity tabling, electrostatic and flotation methods. Output here

commenced with 138 tons valued at Rs 1,835 in 1936, while the total recovery for the decade 1936-46 was 1,342 tons of an estimated value of Rs 17,883. In 1947 and 1948, a further 259 tons were produced, valued in the official returns at Rs 22,277. After a lapse of 27 years, Assamese sillimanite again appeared in the mineral returns for 1948 with an output of 190 tons, which rose to 864 tons in 1949 and to 1,352 tons in 1950. The Pipra deposit in Rewa yielded 110 tons in 1949 and 100 tons in 1950. The total production of sillimanite in India was 1,475 tons, valued at Rs 1,10,048, in 1950, against 974 tons and Rs 73,936 in 1949.

The kyanite deposit of Lapsa Buru, the largest of its kind in the world, has been responsible for much the greater part of India's total production of 463,795 tons of this mineral, valued at Rs 2,70,68,756, since operations commenced in 1924, up to the end of 1953. It is situated in Kharsawan, in the State of Bihar, where the Indian Copper Corporation Ltd has several quarries. None of these are of any great depth and much mineral is recovered from surface deposits, in which the kyanite is found as pebbles and boulders of sizes varying from 1 inch to 6 feet in diameter, buried to a depth of 5 or 6 feet. It is in the form of a massive, medium- to coarse-grained rock of which kyanite itself is almost the sole ingredient, but there are also great beds of kyanite-quartz rock containing segregations of the mineral, often as long, bladed crystals. To a depth of only three feet below the surface it has been estimated that there are still 300,000 tons of massive kyanite available, although an equal tonnage has been raised up to the end of 1951.

Kyanite is known to occur along a belt some 80 miles in length stretching east along the western part of Keraikela Estate, through part of northern Singhbhum, thence through Kharsawan and Seraikela into Dhalbhum, turning to the south-east as far as Shirbai *dungri*. Thus for much of its length this kyanite-bearing territory follows the northern side of the Singhbhum copper belt. In Singhbhum the mineral is won near Ghatsila by Eastern Minerals Ltd, whose operations started in 1934, and at Kanyaluka by E. O. Murray, since 1934. There are also quarries at Badia, Bakra, Uperbenda, Mohanpur, Uparsoli and other localities. Small deposits are known in Manbhum, extending for seven miles in a narrow zone from Ichadih to Salbani, but they are said to be too micaceous for marketing without some form of concentration: more recently, however, D. K. Chandra has found further deposits and he considers that those at Haitiral and Bandudih are well worth further prospecting. Small occurrences are also known to exist in Dhenkanal, Bonai and elsewhere in Orissa. Dumortierite occurs in places with the Singhbhum kyanite rocks and is particularly prevalent at Mohanpur. Dumortierite, besides kyanite, is known to occur in commercial quantities near Panijia in Mayurbhanj. Perhaps the

best deposit of topaz rock, states J. A. Dunn, lies to the south-east of Lapsa Buru, in Kharsawan, but it has also been mined at Ghagidih, in Singhbhum. Segregations of andalusite have been found to the south and west of Daontanri, which is also in Singhbhum.

The resources of other regions have not received the attention given to those of Bihar, but it is known that impure kyanite-topaz-dumortierite rocks occur at several places in the Bhandara district of Madhya Pradesh. Kyanite-quartz rocks crop out at Devarakonda and other places in the Nellore district of Andhra, according to V. Swaminathan, and coarse-bladed kyanite has been found near Chundi, 25 miles from Singaraykonda in the same district. The Krishna Mining Co. owns kyanite quarries near Saidapuram, in the Rapur taluk of Nellore, where the mineral occurs in long, thin blades in mica schists. Small amounts of this variety have also been exported from time to time from the Hassan district of Mysore, and from Ajmer-Merwara. Corundum-kyanite rock with 63 to 65 per cent of alumina is exploited near Makavalli, in the Hassan district of Mysore, where the known reserves total some 20,000 tons. Flattened boulders of massive, coarse-textured, rock kyanite, up to three feet in diameter, have recently been found, though not *in situ*, $3\frac{1}{2}$ miles south of Mercara, in Coorg. The mineral is a constituent of the local gneisses, often occurring in them in the form of small knots and lenticles.

The theory has been advanced by J. A. Dunn that the kyanite and related minerals of northern India are derived from the metamorphism of bauxite or similar clays of sedimentary origin, and the extraordinary persistence and regularity of the Singhbhum belt in which they occur suggests the presence of a zone in the Archæans containing lenticles of such aluminous rocks.

Pure kyanite should contain 63·2 per cent of alumina, and the commercial standard used in the United States of America has been fixed at 58·7 per cent. Some varieties of the mineral, from both Singhbhum and Kharsawan, frequently contain up to 68 or 69 per cent of alumina, betraying the presence of finely divided corundum

AVERAGE ANNUAL PRODUCTION OF KYANITE IN INDIA, 1924-53

PERIOD			QUANTITY	VALUE
			(tons)	(Rs)
1924-8	..	..	1,488	11,026
1929-33	..	..	5,107	73,034
1934-8	..	..	27,372	5,84,651
1939-43	..	..	14,566	3,21,789
1944-8	..	..	16,255	5,55,265
1949-53	..	..	27,971	38,67,986

with the kyanite, an association which may be advantageous to the user. Some Indian producers market three distinct types—a high-grade containing 62 to 64 per cent Al_2O_3 , a medium-grade with 58 to 62 per cent and a low-grade containing from 54 to 56 per cent of alumina.

Until 1938 the whole of India's production of kyanite was exported, but in that year 'sillimanite blocks', for use in Indian glass factories, bricks and other refractory articles began to be made both by Burn & Co. Ltd at Raniganj and by the Fireclay & Silica Works at Kumardhubi. The amounts so consumed averaged 854 tons per annum for the six years 1938 to 1943, and 1,260 tons for the five years ending 1948. Exports of kyanite are now controlled, and in 1950 were limited to an overall annual quota of 20,000 tons of all grades.

Considerable quantities of Indian kyanite reach the United States of America, the average for the five years ending 1943 being 7,468 tons, though in individual years the tonnage has sometimes exceeded twice this amount. War conditions and lack of shipping interfered seriously with this as well as other branches of the foreign trade. In the United States it led to increased production of domestic kyanite, to attempts to form products from fine-grained Virginian mineral, comparable with those made from the large-grained Indian varieties, and to the substitution of calcined andalusite and topaz.

The leading position which India has hitherto occupied in the kyanite trade is being challenged by other countries; moreover, other mullite products are already in the field as competitors of those made from kyanite and its associated minerals: synthetic sillimanite is now manufactured from properly proportioned mixtures of suitable clay, fused alumina, aluminium hydroxide and feldspar. It is in the interests of India, therefore, that the export of these raw minerals from her unique deposits should be replaced as far as possible by the sale of processed products, and, in due course, by goods manufactured from them. For instance, a few years ago, when Indian kyanite was selling at Atlantic ports in the United States of America at \$30 per short ton (plus a small premium for grades low in iron), a calcined, finely ground product, low in iron, was bringing \$78 a ton. In her modern refractory works and in the skill of her own specialists the country surely possesses the ways and means not only to meet the growing demands of her own glass and other industries, but to make finished products acceptable to overseas markets at competitive prices. Much kyanite has been won from scattered surface debris and from boulder deposits in the subsoil; too little attention has hitherto been paid to the more important rock sources from which they originate. It is true that thick, superficial coverings make this task difficult, but it is necessary to undertake it all the same. Quite apart from this, there are possibilities of finding further deposits

in Singhbhum, especially in the extensions of the demarcated belt beyond its present limits in the Porhat. More attention should also be paid to Indian andalusite occurrences, such as those of the Mulkalpalle-Dandigundal belt in the Yellandu taluk of Hyderabad.

ZIRCON

The natural silicate, zircon, ZrSiO_4 , which contains 67.2 per cent of zirconia and 32.8 per cent of silica, is stable to about 1800°C ., when it dissociates into zirconia, one of the most refractory substances known, and a siliceous glass, the change being accompanied by an increase in volume of some 25 per cent. Both zircon and the natural oxide, baddeleyite, ZrO_2 , are used to an increasing extent in the manufacture of refractories of many kinds, including bricks and shapes for metallurgical, heat-treatment and electrical furnaces, burner blocks, molten-metal-pouring tubes and nozzles, high-temperature saggars and crucibles. Zircon refractories have a comparatively low coefficient of expansion, fairly high thermal conductivity, adequate strength, and high refractoriness under load, a combination of properties accounting for their spalling resistance. They are also said to have a good resistance to most coal ash slags, to lead oxide slags, to molten calcium metaphosphate and to be very suitable for aluminium remelting furnaces, but they do not withstand the action of iron slags very well. Zircon crucibles are used in the melting of platinum and platinum-rhodium alloys in high-frequency induction furnaces. Graded zircon sands, mixed with suitable bonds, such as plastic refractory clays, with or without the addition of sodium silicate, are used as ramming cements, plasters and protective coatings. They are also utilized as foundry sands. 'Zircon may also be bonded with hydrolysed silicon ester to provide a quick-setting refractory cement. Such cements find application in the preparation of refractory moulds by the lost-wax process' (F. H. Clews & A. T. Green). Zircon porcelains find a place in sparking plugs, high frequency insulators and laboratory ware, as well as in some types of heat- and chemical-resisting glasses.

Large transparent crystals of zircon may be of value as precious stones and are described under GEMS. The distribution of the mineral in India and its uses as a source of its parent metal are considered under ZIRCONIUM.

TALC

Talc is a hydrated silicate of magnesia, $3\text{MgO} \cdot 4\text{SiO}_2 \cdot \text{H}_2\text{O}$, a very soft, sectile mineral most familiar in its compact, massive form of steatite (soapstone), or potstone. When strongly heated the water content is driven off and the mineral breaks up into clinochstatite and free silica, the former being another silicate of

magnesium with the formula $MgO.SiO_2$, and a hard substance practically infusible at ordinary temperature ranges; indeed, its name is derived from a Greek word meaning *opponent* in allusion to its refractory nature. Clinoenstatite is of course the monoclinic, dimorphic form of the more familiar orthorhombic pyroxene which bears the same name.

The ancient craftsmen of the Mohenjodaro and Harappa civilizations were well aware of these properties of talc five thousand years ago, for they exercised their skill on steatite, engraving their stamp-seals with representations of animals and mythological scenes, before subjecting the carvings to heat by which they acquired hard, white, lustrous, enamelled surfaces. Small sculptures, ornate bosses and vessels were also made from the mineral during those early times. It has been an age-long custom, which persists to the present day in India, to carve and then to fire, pots, bowls, plates and other culinary articles of talc. Such calcined talc, known in the trade by the misnomer 'lava', is still used for the tips and nozzles of gas-burners, the identical purpose for which the mineral was first exported from India some 70 years ago.

Its unique properties lead to multifarious uses but here we consider only those concerned with the ceramic or refractory industries, leaving the others to be outlined in another chapter. Steatite slabs are employed as linings for various kinds of stoves, ovens and fire-boxes. Sawn blocks of soapstone are used in Canadian wood-pulp and paper mills as linings for the alkali-recovery furnaces and kilns. Bricks made from crushed steatite, bonded with silicate of soda, form the reverberatory furnaces in which the crude lead bullion is softened before being desilverized, at the Port Pirie refinery of Broken Hill Associated Smelters Ltd in South Australia. The temperature-control furnaces at these works are of similar type.

Within the last few years, pure talc of 'lava' grade has assumed a new importance owing to its adoption for the manufacture of low-loss ceramic materials required for high-frequency insulation in all kinds of radio, radar, television and related instruments. Cut blocks of the pure, solid mineral, capable of being intricately machined or threaded, or talc in the powdered form, free from any admixture, which could be die-pressed in a dry or semi-dry condition into the complicated shapes required by the electronic industry, were of critical strategic importance during the last war and commanded prices far in advance of all the other market varieties.

Steatite bodies for use in electronic equipment should contain sufficient talc to form a crystalline network of clinoenstatite after firing, and in practice they often start with 80 to 90 per cent of the mineral. For ease in working, small quantities of plastic kaolin are incorporated, but the addition of equally small amounts of

potash feldspar for fluxing purposes has been superseded by the use of barium or magnesium carbonates, or both. Clinoenstatite bodies have better electrical, volume resistivity as well as greater tensile, compressive and impact strengths than porcelain.

When properly proportioned mixtures of talc and clay are fired the magnesium aluminium silicate, cordierite, $2\text{MgO} \cdot 2\text{Al}_2\text{O}_3 \cdot 5\text{SiO}_2$, is formed and it is a compound which possesses an extremely low thermal expansion. 'Consequently,' in the words of S. B. Roy and Y. P. Varsney, 'cordierite-containing bodies do not easily fracture when subjected to sudden temperature changes and show high thermal shock-resistance.' They are employed, therefore, in the manufacture of cooking ware, heat radiator parts, stove fronts, burner tips, thermo-couple insulators, and for many other articles compelled to undergo repeated and rapid heating and cooling, such as the plates of electrical heaters and the cores of electrical resistors. Talc-clay bodies have also been found effective against 'crazing', a term applied to the development of minute hair cracks in the glazes of wall tiles and other porous bodies through the absorption of moisture. It is unfortunate that the nearer the talc-clay mixture approaches theoretical perfection, the shorter becomes its permissible firing range, that is to say the difference between the correct firing temperature and the temperature at which softening begins, though to widen the range other materials such as zircon are sometimes added to the batch. The dielectric properties of cordierite bodies do not differ greatly from those of porcelain, but they are still useful for parts of electronic apparatus whose dimensions must not change appreciably with alterations of temperature.

Bricks composed predominantly of forsterite, $2\text{MgO} \cdot \text{SiO}_2$, have their special applications as refractories, particularly in the roofs of copper-smelting furnaces. They are made by firing mixtures of talc and magnesite to temperatures of 1400° to 1500° C., when the excess silica of the talc reacts with the magnesia to form forsterite. In place of talc, serpentine, olivine or dunite may be employed, though in these cases the forsterite will be contaminated with more or less fayalite, its corresponding iron silicate. Dunite is a member of the peridotite family of rocks, already mentioned under CHROMIUM. Extensive outcrops of it occur in the higher hills near Dras, Bembat and Tashgam, in Kashmir, but they are only approachable by a bridle track over the Zoji Pass (11,200 feet).

Prospectors should be warned that the mineral pyrophyllite greatly resembles talc and is easily mistaken for it. It, however, is a hydrated silicate of aluminium, $\text{Al}_2\text{O}_3 \cdot 4\text{SiO}_2 \cdot \text{H}_2\text{O}$, which is classified as one of the clay minerals by some authorities, and it is used, particularly in the United States of America, in the ceramic and refractory industries for purposes indicated by its aluminous character and physical properties.

THE OXIDE REFRACTORIES

Most of the refractory materials already described are for use in temperatures below 1700°C. ; for higher temperatures still recourse must be made to the pure oxides, alumina, magnesia, beryllia, zirconia or thoria, and as India is unusually plentifully endowed with the minerals from which these are made, it is necessary to describe them briefly here. In mentioning their respective melting points it should be borne in mind that their limits of practical application naturally lie somewhat below these high temperatures.

Alumina (corundum), Al_2O_3 , with a melting point of 2010°C. , is the most widely employed member of the whole group and in the sintered form, often termed 'sintered corundum', is made into sparking plugs, muffles, pyrometer tubes; fine tubes, rods and insulators for vacuum tubes of all kinds; crucibles, boats, dishes, special bricks for high-temperature linings, etc., as well as for mortars, wire drawing dies, thread guides, gauge blocks, fine hones and grinding-wheel truing discs, uses which it owes to its great hardness. It was also made into experimental blades for gas turbines in Germany during the last war. Alumina wares of such kinds are fashioned from slips cast into plaster moulds, the slips themselves being prepared from alumina, of the quality used for the manufacture of the pure metal, calcined and ground to a very fine powder (0.5 to 3 microns), the resulting mud having been digested with hot, dilute, hydrochloric acid and then cleansed by decantation. For extruded articles, the dry, ground alumina is mixed with a gel formed from aluminum hydrate and hydrochloric acid. Jollying and pressing methods are also employed for suitable shapes. In some cases small admixtures of organic bonds are used, such as gum or dextrine. Alumina wares of these types contain 99.5 per cent or more Al_2O_3 , and it is said that in strength no other ceramic product can compete with them, that they have high dielectric properties at elevated temperatures, and marked resistance to sudden temperature changes. Some varieties of porcelain containing from 50 to 70 per cent of calcined alumina and the remainder kaolin, fired at temperatures around 1750°C. , are claimed to be impervious to gases without glazing.

Fused alumina of various kinds and grades is made in electric arc furnaces, the products after crushing and grading being utilized in both the refractory and abrasives industries. Fused white varieties are made from pure, calcined alumina; brown and black kinds from bauxite with which anthracite has been mixed to reduce the iron contents, and from which ferro-silicon, generally containing 16 to 18 per cent of silicon, is recovered as a by-product.

Alumina is also used in the manufacture of synthetic spinel, $\text{Al}_2\text{O}_3\cdot\text{MgO}$, by fusion with calcined magnesite in the electric furnace. This substance has a melting point of 2130°C. , and can

be used up to temperatures in the neighbourhood of 1900° to 2000° C. It is said to possess a low thermal conductivity and resistance to thermal shock with an electrical resistance similar to that of alumina.

Some of the properties of fused magnesia are described under MAGNESITE but it remains to add that it is made from pure, calcined magnesite in furnaces similar to those used in the manufacture of fused alumina, and that it can be utilized in temperatures up to 2400° C.

Beryllia, BeO , has a melting point of 2570° C., and its limit of application lies about 2400° C. It can be formed into porcelain-like bodies useful for crucibles and boats for high-temperature work. Its resistance to marked fluctuations of temperature is superior to that of most other materials. Other properties of this refractory oxide are mentioned under BERYLLIUM.

When the natural silicate zircon, ZrSiO_3 , is heated to about 1775° C. it dissociates into zirconia, ZrO_2 , and a siliceous glass. Various bonds have been used in the manufacture of zirconia bricks produced in this way, including a proportion of the mineral itself in a more finely powdered condition than the rest of the mix. Clay and alumina are not suitable as bonding materials. The applications of these refractories are described under ZIRCON. Zirconia itself has a tensile strength surpassing that of alumina at temperatures between 500° and 1200° C. It is an amphoteric oxide, resistant to the action of both acidic and basic melts; moreover, it withstands the action of reducing gases and is used in the form of crucibles for platinum melting and the preparation of alloys of the metals of the platinum group. Small quantities of magnesia may be incorporated with zirconia without impairing its safe working limit of about 2500° C.

Thoria, ThO_2 , with a melting point of 3050° C. and a safe limit of application of about 2700° C., is an oxide of extreme refractoriness. In addition, it has a very high specific gravity, is comparatively inert towards chemical reagents, possesses a high coefficient of expansion and a low conductivity. It is fused in the carbon arc and made into crucibles used in the refining of the precious metals.

GLASS SANDS

Ordinary glass is a mixture of the silicates of sodium and calcium in a solidified, undercooled condition, made by melting together pure sand, limestone and sodium carbonate in the correct proportions. Glasses for special purposes contain other elements in place of the sodium and may include, amongst others, potassium, lead and barium, as well as boron in place of some of the silicon. Common window glass, plate glass and glass for bottles and tableware are soda-lime silicates made to varying prescriptions. The hard Jena glass of chemical laboratories is a potash-lime glass.

Flint glass is a lead-potash silicate; lustrous and with a higher index of refraction than many other glasses, it is used in lens-making and for ornamental cut glass. Crown glass is another variety containing potassium or barium and also used for optical instruments. As this note is primarily concerned with glass sand, it should be stated at once that the silica content of most of the glass made in India today varies between about 72 and 78 per cent.

An inferior glass has long been made in India by fusing the alkaline efflorescence known as *reh*, which in its impure state in certain localities contains sufficient silica and lime for the purpose, though sand is sometimes added in that form, or as powdered quartz. Archaeologists have not yet decided when glass was first made in the country, but when it is recalled that frits and glazes were used by the faience makers of Harappa times, it is unlikely to have been very long after that period. A prehistoric glass works site is said to have been located recently at Kopia, Bustee district, Uttar Pradesh. According to Dr E. Rosenthal, the remarkable, translucent, ceramic products made in China in the time of the Sui Dynasty (A.D. 581-617), and at the beginning of the following Tang Dynasty (A.D. 618-906), 'probably the first real china ever made', were made by 'skilful Chinese workmen trying to imitate glass articles which had found their way to China from India'. Whether this is apocryphal or not, the fact remains that the beginnings of the glass industry in India lie in the very remote past, and that crude glasses have been made throughout the centuries, mainly for the manufacture of *churis* (bangles).

In early Muslim times a colony of glass-blowers (*shishagars*) was established at Firozabad in Uttar Pradesh, while the glass-workers of Gazulapet and Mamkonda, in Hyderabad, have practised their trade from an unknown past. In 1856 there were two glass factories near the Lonar soda lake of the Buldhana district, Madhya Pradesh, and an indigenous industry has existed for at least 130 years at Matrod, in the Chitaldrug district of Mysore, using local quartz and soda from surface efflorescences of the same district. Similar examples might be quoted from the Punjab.

Modern methods of manufacture commenced about 64 years ago; between 1890 and 1900 five factories were established, followed by 16 more between 1906 and 1913. Some of them failed and the rest were languishing when the first world war (1914-18), by stopping imports from abroad, brought about a revival, so that by 1918 about 20 factories were at work. Foreign competition soon reasserted itself, and, in 1923, led to the imposition of an import duty of 30 per cent on glass bangles, beads and false pearls, and of 15 per cent on glass and glass-ware, the latter being increased to 20 per cent in March 1931, and then to 25 per cent in September of the same year. By 1932 there were 59 factories at work, 26 of which were entirely occupied with the manufacture of glass bangles, and by 1938-9 the number had grown to about 100, distributed as

follows: United Provinces 38, Bengal 28, Indian States 11, Bombay 19, Punjab 3, Madras 1, Delhi 1. The second world war, by causing the cessation of imports from Czechoslovakia, Germany, Belgium and Japan and by greatly restricting those from the United Kingdom and the United States of America, enabled the home industry to develop rapidly though there was the inevitable setback as trade became more normal again in the post-war years. The Tariff Board, which had already reported on the industry in 1931, submitted the results of another investigation in 1950, and this resulted in the manufacturers of sheet glass obtaining a protective duty of 45 per cent *ad valorem* for a period of two years. During the war period the number of glass factories increased to 174, and production rose from 6 million square feet of sheet glass and 43,000 tons of glass-ware to 13 million square feet and 1,10,000 tons respectively. In 1950 there were 224 glass factories in the Indian Union alone, of which 131 were producing glass and glass-ware and 93 were entirely devoted to the manufacture of bangles, beads and 'pearls': as regards their distribution, 114, including 90 of the bangle factories, were in Uttar Pradesh; 34 in West Bengal, 32 in Bombay, and the rest scattered in various parts of the land. With the exception of the bangle-makers, the majority produced containers or lamp-ware. There were also at that time some 20 or 30 works making table-ware as well as containers, 3 manufacturing sheet glass and about 9 specializing in scientific glass-ware.

The term 'factory' as generally understood may be misleading, for the majority of them are small workshops of the cottage-industry type, with a daily outturn of two to four tons of glass made up into the lowest-priced articles, of which bangles and lamp glasses form the great bulk. There are, of course, a few well-equipped works. Early in 1948, machinery for the production of scientific glass-ware had been imported from Europe and America, as well as automatic bottle-making machines for a factory in West Bengal and others for glass ampoules for a works in Bombay. Machinery for the manufacture of hollow ware of various kinds followed later. In 1950 three factories were making sheet glass: at Sodepur near Calcutta, at Seraikela in Bihar, and at Bahjoi in Uttar Pradesh; their combined total capacity was then 15 million square feet per annum. The first attempt to manufacture glass bottles in India was made in 1892, when a factory was started at Jhelum by the Murree Brewery Co., but the experiment was not a success. Bottles are made today at Sodepur, Banaras, Ghaziabad (near Delhi), Himatnagar (in Idar) and Baroda. Several works, particularly in West Bengal and Uttar Pradesh, make laboratory ware, beakers, flasks and the like, from heat-resisting glass, as well as electric light bulbs, glass tubing, ampoules and syringes. Others turn out pressed tumblers, plates and tiles, while experimental quantities of optical glasses have been successfully manufactured. Decorative glasses are a speciality of the centuries-old centre of Firozabad. Moulds for mouth-blown

articles and semi-automatic blowing machines are now made in the country. During the last war the industry was able to meet all the requirements of the Medical Services.

Glass sands must be free from impurities and should also be of proper grain size to facilitate chemical reaction during fusion. The famous Fontainebleau sand contains 99.7 per cent of silica, 0.19 of alumina, 0.002 of iron oxide and 0.14 per cent of lime, while 85 per cent of it consists of particles between 0.25 and 0.5 mm. in diameter. Many of the better-known European and American glass sands contain over 99.5 per cent of silica and are used for the finest wares. Sand for plate glass should contain at least 98.5 per cent silica, but for commoner grades, such as cheaper window glasses and for bottles, such a high silica percentage is not essential. Sands containing up to 0.02 per cent of iron oxide (Fe_2O_3) give colourless glasses; from 0.02 to 0.05 an almost colourless glass. Very pale green tints appear when the iron oxide content reaches 0.05 to 0.10, but it can be neutralized at some little cost in brightness and transparency by suitable correctives such as manganese dioxide. Decolorizing is not successful when the iron oxide content exceeds 0.1 per cent; from 0.1 to 0.3 per cent imparts pale green tints; 0.3 to 1 per cent gives green shades, and when the iron oxide content is over 1 per cent, dark green glass results.

The regular grading of the sand is also important and the general average of the grains should be fine. At least 70 per cent of the sand should consist of grains between 0.25 and 0.5 mm. in diameter, or, in other words, all the sand should pass a 20-mesh sieve, 95 per cent pass a 30-mesh sieve and remain on a 120-mesh sieve; sand passing a 120-mesh sieve should be rejected. A 30-mesh sieve is one containing 30 holes per linear inch and with the intervening wire the same size as the mesh. Although alumina may be useful for special purposes, for ordinary usage glass sand should not contain more than 0.5 per cent. Magnesia, like alumina, increases the viscosity of the melt and so requires higher fusion temperatures. Green bottle glass can of course be made from inferior sands rather high in iron oxide.

Many varieties of sands, crushed sandstones, quartz and quartzites have been used in Indian glass works and many more have been suggested; from them only a selection can be attempted here. The crushed friable quartzites of Panijia and Souri, in Mayurbhanj, Orissa, supply sand for several glass works near Calcutta; similar quartzites occurring near Taldanga, in the Burdwan district of West Bengal, furnish further supplies. The white, Gondwana sandstones of Patharghatta Hill, close to the Ganga in the Bhagalpur district of Bihar, yield a good glass sand practically free from iron compounds but rather high in alumina. One of the more important actual and potential sources of supply lies in the Dhandraul Quartzite, which forms the topmost horizon

of the Kaimur Series of the Vindhyan System in the Son valley. It is worked in the Chakia area of Banaras, between Murari and Balabeliat, in the Jhansi district, and especially in the neighbourhoods of Shankargarh, Lohgarh and Bargarh, popularly known as the Naini area, in the Banda and Allahabad districts of Uttar Pradesh. It also occurs in Rewa, further to the west and south-west. Many of the glass factories, and, incidentally, the manufacturers of sodium silicate, in northern India and some of those in Bengal use its sand. In a detailed study of the occurrences of the Naini area, published in 1951, D. R. S. Mehta has shown how the quartzite under its thin covering of soil has become friable to a considerable depth through the agency of percolating rain-water, leaching out most of the iron content and loosening the silica cement binding the quartz grains together. During the hot season the iron-bearing solutions rise to the surface by capillary action, there to be deposited as a hard, thin, ferruginous 'pan', beneath the surface soil. The friable quartzite is obtained by hammer-and-chisel methods from small surface workings, handpicked, crushed by wooden beaters and sieved. Between Manikpur and Bargarh there are at least 14 important areas where good-quality sand is obtainable, and the gross reserves of the Rewa-Banda region alone are tentatively placed at 110 million tons, about one third of this quantity being in Banda and the rest in Rewa. The examination of 45 samples collected by Mehta shows that the bulk of the sand is not coarser than 30 or finer than 100 mesh. 'The ferric oxide content', he writes, 'in every case is above 0.1 per cent, which is rather too high for optical and the best crystal glass. It is well within the permissible limit of 0.2 per cent for plate glass in the majority of samples, while almost all are suitable for the manufacture of window glass, white bottles, etc.' There are still wide regions in which this same Dhandraul Quartzite is known to occur, but which still await detailed investigation. They include the Robertsganj plateau, in the Mirzapur district of Uttar Pradesh, extending westwards into Rewa, through Govindgarh and Satna, into the Damoh district of Madhya Pradesh, as well as through Panna and Bijawar into Jhansi.

D. R. S. Mehta has also examined the glass sands of Barodhia, in the Bundi district of Rajasthan, and found them to be derived from a zone of soft grit occurring amongst the sandstones and quartzites in the Lower Bhandar Stage of the Vindhyan System. The zone has been traced for 1,400 feet, and varies in width from 50 to 300 feet; it has been worked 'in the crudest way imaginable' by burrows descending to 25 feet, and can reasonably be assumed to extend to a depth of at least 50 feet. The available reserves total about 1,162,000 tons. Some of the samples from this deposit are low enough in iron content to be regarded as suitable for optical and crystal glass manufacture; most are suitable for ordinary types of glass-ware, and others can be greatly improved by washing

out the finer portions. The Jaipur glass works obtain supplies from their own quarries near Sawai Madhupur and Jatwara.

Soft Cretaceous sandstones of local occurrence are used by the works at Himatnagar, Idar, Bombay, and similar rocks at Sankheda and Pedhamali, in Baroda, furnish material for the glass works there. The well-known Songir Sandstone of Baroda contains over 99 per cent of silica and about 0.04 per cent of ferric oxide. The sandstones of Dhrangadra, in Saurashtra, are of lower grade than those just described but have been utilized for the manufacture of bottles. Certain recrystallized sandstones of the Kaladgi Series found near Shindikurbet, in Belgaum district, Bombay, are said to be suitable for bangle-making.

Good-quality sand has been found between Bonnerupalem and Pandillapalle, near Chirala, Guntur district, Andhra, and in Shertallay, Travancore, while material from an old sea beach at Ennore, in the Chingleput district of Madras, also has its advocates. Friable quartzites, popularly termed 'silver sand', occur in parts of the Chiknayakanhalli Schist Belt of Mysore and serve a local glass industry, but for the glass works of Bangalore vein quartz is quarried and crushed at Sonnehalli, near Kengeri, in Bangalore district. The glass works of Hyderabad, Deccan, also make use of local quartz veins, the mineral from which is stated to average about 99 per cent silica and 0.20 per cent ferric oxide.

Veins of transparent quartz of high purity are of frequent occurrence in the Singhbhum granite and there are many others in the Ranchi, Manbhum, Hazaribagh, Santal Parganas and Monghyr districts of Bihar, Patna, Sambalpur and Sonepur regions in Orissa, in the Visakhapatnam district of Andhra and in numerous other places. Quartzite boulders from the Upper Siwalik conglomerates of the Himalayan foot-hills are collected about Hoshiarpur to be crushed and sent to the glass works of the East Punjab. Enormous quantities of boulders of white quartz lie in the bed of the Tawi river, near Jammu, Kashmir. The infra-Trias Limestones near Garhi Habibulla and Muzaffarabad, in Kashmir, are silicified and said to be capable of yielding large masses of soft, granular, almost powdery silica. G. N. Dutt states that friable white quartzite of glass-sand quality occurs at Ranimatta, in the Dai Lekh district of western Nepal. To conclude this incomplete list as far as the Indian Union is concerned, good sands are obtainable from friable sandstones at Madh, in Bikaner, Rajasthan; local supplies are used in glass works at Jabalpur, Madhya Pradesh; and the factory at Barang, near Cuttack, Orissa, employs Gondwana sandstones from Naraj and Talgar, on the Mahanadi.

Certain selected layers of sandstones both of basal Eocene and Middle Jurassic ages, in the Surghar Hills of the Mianwali district, West Pakistan, are suitable for better-quality glass manufacture after treatment. Useful sand is obtainable from certain iron-free layers, 20 or 30 feet thick, in the variegated Jurassic sandstones,

and as these extend for 15 or 20 miles there is no possibility of exhaustion. According to M. I. Ahmed, there are very great reserves of glass sands near Paniala, in the Dera Ismail Khan district of the North-West Frontier Province. Crushed sandstones from Jungshahi, Tatta district, Sind, have been used by glass works in Karachi and Hyderabad (Sind). Superior-quality sands are found in the same district, south of the Meting-Jherruck road, in the Sonahri Beds which lie unconformably below the Meting Limestone and above the Upper Ranikot. They have been the subjects of recent reports by A. H. and A. M. Khan and W. Ahmed of the Geological Survey of Pakistan.

AVERAGE ANNUAL VALUES OF INDIA'S GLASS IMPORTS, 1898-1949

PERIODS	AVERAGE	ANNUAL VALUES
	<i>Rs</i>	<i>£</i>
1898-9 .. ..	....	441,529
1903-4 .. ..	....	661,377
1907 .. ..	....	over 900,000
1908 .. ..	....	" 800,000
1913 .. ..	....	" 1,300,000
1909-13	1,58,66,820	1,057,788
1914-18	1,30,80,795	872,053
1919-23	2,46,92,330	1,935,679
1924-8	2,56,03,950	1,899,546
1929-33	1,69,17,523	....
1934-8	1,37,07,404	....
1939-43	66,45,377	....
1944-6	62,00,667	....
1947-9*	1,48,45,994	....

* Fiscal years 1946-7 to 1948-9.

The figures given in the table above demonstrate that in the 15 years ending 1938 the annual value of India's imports of foreign glass fell by over 46 per cent from Rs 256 to Rs 137 lakhs. The period of the second world war witnessed a further diminution to less than half this amount, but, unfortunately, the value of the imports for 1947-9 are back to those of the pre-war period once more.

An analysis of the detailed returns up to the outbreak of war in 1939 shows that bangles, beads and false pearls, those articles of feminine adornment which in the years 1924-8 accounted for nearly half (48·4 per cent), had by 1934-8 fallen to less than one third (31·3 per cent) of the total imports of foreign glass products. Utility goods, over the same period, had increased—bottles from about 14 to 19·6 per cent, sheet and plate glass from 12 to 17 per cent, wares of unspecified descriptions from 12·2 to 21·6 per cent. Glass globes, lamp glasses and funnels, on the other hand, fell

from 7.1 to 4.4 per cent of the total imports; table-ware maintained the same proportion of 3.9 per cent; scientific glass-ware and Government imports showed little change, the percentages being 0.8 to 0.9 and 1.7 to 1.2 per cent, respectively, from the beginning to the end of the decade. During the war years all classes of imports suffered severely, and by 1943 the foreign trade in fancy articles such as bangles and beads had practically ceased, only to exhibit marked revival again in 1946.

During the periods 1926-8 and 1934-8 India continued to buy most of her foreign glass supplies from Japan and the six European countries named below. Japan's share in this trade increased from 26.5 to 47.7 per cent of the total over the years in question, at the expense of the others concerned. Their imports decreased from 10 to 8.4 per cent for the United Kingdom; from 17 to 12.4 per cent for Germany; from 27.5 to 16.5 per cent for Austria and Czechoslovakia; from 3 to 2.1 for Italy; from 6 to 3.6 for other unnamed countries; while Belgium more or less maintained her position with 9.3 compared with 10 per cent. Over the war years imports from all enemy and overrun countries ceased, and in 1946 the United Kingdom and 'Other Countries' shared the import trade of Rs 109.6 lakhs in the proportions of 68.3 and 31.7 per cent.

In the following table the average annual value of the glass imports (Rs 1,48,45,994) over the fiscal years 1946-7 to 1948-9 are analysed into their separate components, the figures being taken from the Report of the Tariff Board on the Glass Industries, 1950.

AVERAGE ANNUAL IMPORTS OF GLASS MANUFACTURES,
1946-7 TO 1948-9

ARTICLES	AMOUNTS	VALUES in Rs
Sheet and Plate Glass ..	263,731 cwt	79,95,530
Soda-water Bottles	6,427 gross	1,71,451
Other Bottles	144,207 gross	12,33,658
Lamp-ware .. .. .	....	2,31,988
Table-ware .. .. .	....	49,89,175
Bangles .. .. .	....	2,24,192*
	TOTAL ..	1,48,45,994

* Against Rs 27,16,000 for the years 1936-7 to 1938-9.

The Tariff Board estimated the productive capacity of the industry in 1950 as follows: bottles and phials 125,000 tons, lamp-ware 10,000 tons, table-ware (including tumblers) 9,000 tons, pressed ware 4,000 tons, glass shells 10 million pieces, sheet glass

15 million square feet, and bangles 35,000 tons. A recent official estimate regards the installed capacity as about 150,000 tons per annum for glass and glass-ware, and 14,400 tons per annum for sheet glass, equivalent to 23.4 million square feet. The Target Committee fixed the target for 1950-1 for glass and glass-ware at 110,000 tons, though this was revised later to 96,000 tons. The Planning Commission's estimates for 1950-1 envisaged a production of 107,000 tons, to include 86,000 tons of hollow ware, 5,000 tons of sheet glass and 16,000 tons of bangles. By the end of the five-year period in 1955-6, the Commission anticipated that the installed manufacturing capacity for hollow ware would have grown to 232,000 tons, with a production of 174,000 tons, the corresponding figures for sheet glass being 36,000 tons capacity and 27,000 tons production, and those for bangles being 35,000 tons and 17,000 tons, respectively.

The actual output in the last three years is given in the following table.

PRODUCTION OF GLASS, 1948-50

YEAR		GLASS AND GLASS-WARE	SHEET GLASS
		(tons)	(sq. ft.)
1948	..	69,561	6,255,131
1949	..	68,760	3,427,261
1950	..	87,000	9,528,000

The time that India is likely to take to free herself from the necessity of the continued importation of enormous quantities of glass and glass products does not depend on her supplies of raw materials, though much still remains to be done in improving the grading and processing of suitable sands. It will be shortened by the mechanization of the larger factories, by the standardization of the various products, by co-operation within the industry itself, by the advanced training of operatives and by the spread of a sound knowledge of the scientific principles of modern glass technology, in which the Central Glass and Ceramic Research Institute is destined to play a leading part.

ANALYSES OF INDIAN GLASS SANDS

	SiO ₂	TiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	K ₂ O	Na ₂ O	Loss	TOTAL
Patharghatta	96.00	..	1.15	tr.	tr.	tr.	2.85	..	..	100.00
Naini	98.95	0.06	0.39	0.02	0.11	nil	0.08	0.02	0.36	99.99
Sankheda	99.39	0.07	0.11	0.04	0.15	0.05	nil	nil	0.20	100.01
Pedhamli	98.10	0.17	0.84	0.04	0.15	0.07	nil	nil	0.63	100.00
Bargarh	97.58	..	1.52	0.16	tr.	0.18	..	..	0.68	100.12
Ennore	97.53	0.09	1.02	0.04	0.13	0.13	0.38	0.24	0.35	99.91

MOULDING SANDS

Sands which are utilized in foundries to make the moulds in which molten metals are cast should possess a number of special qualities. They must be refractory enough to withstand the temperature of the molten metal without fusing or 'burning on' to the casting itself. This is of special importance in the case of iron and steel, which are cast at higher temperatures than the non-ferrous metals and their alloys. Moulding sands should not contain more than fractional percentages of alkalis and as little lime and magnesia as possible, as they are deleterious fluxing agents. They must have sufficient plasticity, sometimes referred to as 'strength' or 'cohesiveness', to take and retain the shape of the mould. Plasticity depends largely on the amount of clay in the sand and on the presence of the correct amount of water. As large volumes of gases are generated when the hot, molten metal comes into contact with the mould, it must be permeable enough to permit of their escape. Such gases arise from occluded air, from any organic matter present, from water in the bonding clay and from that added in the mixing process. Natural ('green') moulding sands may contain 5 or 6 per cent of moisture, and over 3 per cent of water may have been added to the so-called 'synthetic' sand mixtures to make them workable, and, as water expands to some 1,700 times its own volume of steam, the importance of permeability is easily realized. It is itself dependent on the size and shape of the individual sand grains, on the amount of clay present and its distribution, as well as on the actual packing of the mould. The texture of the sand is of great significance, for besides influencing most of the other qualities it determines the 'finish' of the surface of the casting. Coarser sands are less affected by the action of heat than finer ones and naturally possess greater permeability.

Natural moulding sands, which may contain 80 to 90 per cent of silica grains, with clay and some iron oxide, and little or no silt, possess sufficient binding material to enable their employment with little preparation beyond milling. 'Synthetic' sands are made by mixing pure, washed, silica sands of suitable grain sizes with a binding clay, and for this purpose the bentonites excel, illite-bearing clays give intermediate strength and those of the kaolinite group are the weakest.

When hollow castings have to be made, these portions are formed by separate cores which are fitted into the moulds after the pattern has been removed. The cores are prepared from fine-grained silica sands held together by some organic binding agent, such as linseed oil, dextrine, pitch, plastics and so forth, and they are usually baked in stoves to impart rigidity before use. By this means, during the casting operation, a thin skin of solid metal forms around the core before its organic bond is destroyed, leaving a soft

collapsible mass, easily removable when the casting is taken from the mould.

The durability of a moulding sand is a measure of the number of times it can be used without losing its strength and permeability when again mixed with water. Deterioration caused by burning of the clay bond eventually causes the sand to become 'dead burnt', and in this condition it can be no longer used. In practice it is usual to mill a proportion of fresh virgin sand with that which has already been moulded.

In gravity and pressure die-casting of the lower-melting-point metals, the moulds are made of cast iron or steel, whereas in the new technique of centrifugal pressure casting, according to Sir Charles Goodeve, the moulds are made from sand or other highly refractory material. This allows centrifugal castings to be made of steel and other alloys with melting points too high for pressure die-casting machines.

As magnesium and its alloys when heated are extremely reactive towards air and moisture, precautions have to be taken when making castings from them. This is done by the introduction of inhibitors, either mixed with the moulding sand or applied as washes to the mould surfaces. These surround the molten metal with inert and protective atmospheres and prevent reaction with the air and moisture. Sulphur and boric acid are generally used for this purpose, but the volatile double fluorides are also employed in some foundries.

Mechanical and mineral analyses of moulding sands are of greater value in assessing their properties than elaborate chemical analyses, for in most cases the chemical composition can be judged sufficiently well from a knowledge of the minerals present. Chemical analyses cannot predict physical properties and the specifications drawn up by the Associations concerned in Europe and America are based mainly on physical standards, such as tests for fineness, clay content, moisture content, permeability and compression strength.

Good natural moulding sands are available from the Damuda Series near Raniganj and also from the Barakar area. They are said to occur under the Older Alluvium near Ondal, in the Burdwan district of West Bengal, and there are other deposits near Kumardhubi, Ramkanah and elsewhere in Manbhum, Bihar. In many cases 'synthetic' moulding sands are made by mixing highly siliceous river sands with suitable clays; the Indian Iron & Steel Co. Ltd, for instance, utilizes sand from the Damodar and Barakar rivers for this purpose. Mogra sand from Baghmaidan, near Pandua, in the Hooghly district of West Bengal, as well as material from Damra and Kotaldih, 4 miles south-east of Asansol, and again from Parasnath, in the Hazaribagh district of Bihar, are also used. Friable quartzites near Jamshedpur are used by the Tata Iron & Steel Co. Ltd as foundry sands. Several of the foundries in and

around Calcutta make use of a fine silica sand obtained as a by-product in kaolin production at Mangalhat, Patharghatta and other localities in the Rajmahal Hills. In Madhya Pradesh, the Lameta Sands have been used from time to time. Other high-grade sands are obtained from the Vindhyan Sandstones of Akauria, near Dabhauria, in Rewa and from Sawai Madhupur, in Jaipur, Rajasthan. According to B. C. Roy, weathered Gaj sandstone occurring from 3 to 5 feet below the bed of a stream at Malanka, 6 miles from Bhavnagar in Saurashtra, is worked down to a depth of 35 feet and after removal of thick partings of grey clay, is shipped regularly to Bombay for use in the foundries there. It yields a fine yellow moulding sand which is claimed to be one of the best of its kind in India. There are large reserves of this material.

GRAPHITE

Graphite, plumbago or black lead, the soft modification of the natural forms of carbon, has been mined in Ceylon, albeit in a primitive fashion, for at least 120 years, with an annual output fluctuating between a few scores of tons to a maximum of 34,000 tons per annum. For many decades Ceylon has been the world's principal source of the superior grades of the mineral, the plumbago of commerce. The Archaean rocks of the island are southward extensions of the strata which underlie much of the extreme southern part of India, and graphite occurs in many places, as disseminations in gneisses and limestones; in seams which follow the foliation of such rocks and in true fissure veins which cut across their bedding planes. Discovered in Travancore in 1840, the mineral was mined there in the early years of the present century by the Morgan Crucible Co. Ltd, and between 1901, when regular returns first became available, and 1911 when operations ceased, 35,000 tons had been produced. Many localities are known and include Arumanallur, with a narrow, branching vein in decomposed pegmatite; Avanesswaram, with a vein in garnetiferous gneiss, and Kinpallikonum where the mineral is in a feldspar vein traversing garnetiferous gneiss. Both in Travancore and in the adjoining district of Tirunelveli (Tinnevely), in Madras, graphite has been found in surface lateritic deposits formed from the crystalline rocks below. The most productive mine in Travancore was at Vellanad, in the Nedumangad taluk. The geological features of the Travancore occurrences are held by some authorities to prove that graphite can sometimes originate under conditions which preclude the supposition of its organic origin.

Small parcels of graphite came from the Godavari district of Andhra in the years 1904, 1905 and 1908, and from the Visakhapatnam district of Andhra in 1906, 1910 and 1911, but the total quantity from both was but 452 tons, and by 1912 graphite mining in India was extinct. The first world war (1914-18) stopped the

import trade and led to the opening up of deposits in the Kalahandi district of Orissa, which yielded 510 tons between 1915 and 1919, and in Ajmer-Merwara, whence 1,169 tons were obtained. Another series of sporadic outputs followed between 1919 and 1934, with a further 56 tons from Ajmer-Merwara, in 1920 and 1929; 82 tons from Patna in the Eastern States Agency (now in Orissa), in 1919 and 1920; 47 tons from the Betul district of Madhya Pradesh, in 1920 and 1921; 20 tons from Mysore, in 1922; 1 ton from the Bhagalpur district of Bihar, in 1921, and 11½ tons from the Krishna district of Andhra, in 1931 and 1932. From 1934 onwards production, though still on a small scale, was more regular, increasing from an annual average of 459 tons in 1934-8 to one of 856 tons in 1939-43. For the five years ending 1948 the average was 1,338 tons per annum. Of the 6,578 tons raised in the decade 1934-43, approximately 50 per cent came from Patna, in Orissa; 30 per cent from Mysore; 15 per cent from Madhya Pradesh; 3 per cent from other parts of Orissa, and the rest from Hyderabad and Rajasthan. The total output for the years 1949 and 1950 was 2,681 tons, valued at Rs 1,84,540, and of this amount approximately 53 per cent came from Orissa, 23 per cent from the Kolar and Hassan districts of Mysore, and 22 per cent from the Betul district of Madhya Pradesh. The producing regions of Orissa were Sambalpur, Patna, Koraput and Athmalik in the order named.

The graphite deposits of these parts of Orissa, some of which have been known for over 80 years, as well as those of the Godavari and of the Visakhapatnam and Krishna districts of Andhra, are associated with rocks of the Khondalite Series and sometimes with the charnockites and granitoid gneisses intrusive into them. The khondalites are parashists and include garnetiferous quartz-sillimanite rocks, garnetiferous quartzites, calciphyres and graphitic schists. They are typically developed in the Eastern Ghats region and often contain local concentrations of graphite in veins of varying thickness and extent, irregular lenses and distorted pockets, few of which, however, are of economic consequence. Only a selection of the more important ones can be mentioned here, but before describing them we would recall Dr D. N. Wadia's work in Ceylon, which proved that the more important deposits of graphite there—the embedded masses, veins, lenses and pockets of almost pure graphite—occur in elongated belts traversing the granulitic rocks of a Khondalite Series, in a north-north-west to south-south-easterly direction, or in joint planes which are more or less transverse to this direction.

All the subdivisions of Bolangir-Patna—Patnagarh, Bolangir and Titilagarh—states B. C. Gupta, possess workable deposits of graphite, and at Barghati, in the first-named area, a vein 20 feet long, thickening in strike from 2 to 12 feet, has been followed to a depth of 90 feet in streaky granite-gneiss; at Lahakhan, a vein has

been followed for about 100 feet, and at 40 feet below the surface showed no signs of dwindling. Its crude material averaged 55 to 60 per cent of fixed carbon. In the same Patna district there are numerous surface workings in the vicinities of Budeliaria, Garvarasa, Dhaurakhman and Matupali, from which crude material containing from 40 to 55 per cent of fixed carbon is cleaned and washed in Titilagarh, raising its content to 60 or 70 per cent carbon before disposal.

The graphite pits of the Nawapara subdivision of Sambalpur are located, states B. C. Roy, on bands, veins and pockets of the mineral in a garnetiferous, gneissose schist. Another deposit has been quarried at Sargipali, near Padampur, since 1944.

Both flaky and amorphous graphite have been regularly mined at Majikelam, $2\frac{1}{2}$ miles from Bissam-Cuttack, in Koraput, since 1944. The area is densely forested and the lessee writes: 'Mining is frequently interrupted by the scare of wild animals and high incidence of malarial fevers. Labour is difficult to secure and also inefficient.' There are other deposits at Arugali, Karriguda, etc., in Koraput.

In the Athmalik subdivision of Dhenkanal there are quarries at Bamur, from which crude graphite containing 70 to 80 per cent fixed carbon is obtained, and others at Dhandatopa, the nearest railway station to which is Meramundali on the Eastern Railway.

The well-known occurrence of Peddakonda in the Bhadrachalam taluk of the East Godavari district, Andhra, is almost worked out, but S. Krishnaswamy reports further veins, 6 to 12 inches in width, in khondalites and feldspathic gneisses, near Kaitanuru and Chokkanapalle in the same taluk. The quarry of the Indian Plumbago Co. at Nagavaram Mutha, near Ellore, in the West Godavari district, has been producing since 1929. As raised, the crude mineral contains from 40 to 65 per cent carbon which is processed to yield flake graphite of 92 to 93 per cent carbon for lubrication purposes; crucible lump with 80 to 85 per cent carbon, sold to crucible makers in Rajahmundry and Bombay; foundry facings with 30 to 60 per cent carbon, and high-percentage powders for battery manufacturers. In the Visakhapatnam district graphite has been mined at Lenkalapalem, near Tardi, since 1948, and obtained from surface workings in the Golugonda taluk since 1942.

The Mysore mineral, which is fine-grained and 'amorphous', comes mainly from low-grade carbonaceous clay schists intercalated with quartzites in the Kolar schist belt, near Ganacharpura, in the Bangarapet taluk, or from well-defined veins in immediate contact with igneous rocks such as diabase and granite. Flaky graphite occurs in thick lenses in crystalline schists near Mavinhalli and Torvalli, in Mysore district. Very large tonnages of low-grade graphitic schists also exist at Torvalli, which is near Sargur, in the Heggaddevan taluk.

The graphite of Madhya Pradesh comes from a band of graphitic phyllites, found in a zone up to 10 feet wide, some three miles north of Betul. They have a carbon content varying between 18 and 30 per cent.

Several occurrences are known in Rajasthan, as, for instance, at Lotiana, in Jaipur, where a band of graphitic schists was at one time pitted extensively. Similar schists occur near Buchara, in western Jaipur, and others have been worked in Kishengarh as a source of black pigment. Ajmer-Merwara has mines at Gudha, Hatundi and other places in Ajmer *tahsil*, and at Kesarpura, Kalat Khara and other localities in the Beawar *tahsil*. In Rajasthan, graphite is usually found in schists and limestones near the base of the Delhi System, and it is generally of low grade.

The mineral has also been reported from Paloncha in Warangal district of Hyderabad, from schists near Almora in Kumaun, in veins between Tsungtang and Lachen in Sikkim, in the slaty formations of Chota Kazinag, and in phyllites and slates south-east of Relhian in the Uri *tahsil* of Kashmir.

According to S. Tayyab Ali, there is a rich vein of graphite, 150 feet in length and 8 to 18 inches thick, about one mile north-east of Shah Salim, in Chitral, Pakistan. Thinner veins occur near Momi, close to the contact of intrusive granite with shales and phyllites. In 1885, Griesbach noted numerous layers of graphite in shales north of the Tor Sapper in the Khyber Agency, but A. L. Coulson, after inspecting those near Shahdimena and east of Lowaramena, in the Mullagori country, in 1936, found they had no economic value.

Graphite is often freely distributed through certain bands of the crystalline limestones of the Mogok Stone Tract, Burma; unsuccessful attempts have been made from time to time to work richer lenticles near Wabudaung, Kyaukkyi, Onzon and elsewhere, in the Thabeitkyin subdivision of the Katha district.

Graphite is a good conductor of heat and electricity and like other forms of carbon is practically infusible, undergoing no change when heated in the absence of oxygen, up to temperatures of about 3600° C., when it is volatilized. At one time most of the world's output of graphite was consumed in the manufacture of crucibles for 'crucible steel' making, a process now largely replaced by electric furnace methods. Graphite crucibles are still employed, however, for some special steels and for the melting and refining of many non-ferrous metals and their alloys, for they are very refractory and possess high heat conductivity and resistance to sudden changes of temperature. In their manufacture the graphite is mixed with plastic fireclay and sand; moulding is done by hand or by machine, and, after drying, the firing is done in a reducing atmosphere. The graphite content is usually about 50 per cent but may vary between 25 and 75 per cent. Graphite crucibles are made by the Indian Crucible Co., at Malad, in Bombay, from

the mineral mined in the West Godavari district of Andhra, and they are used in the factories of Ahmedabad, Baroda, Surat, Bombay, Poona, Nasik, Belgaum, Madras, Bangalore and elsewhere, for a variety of metallurgical and tempering operations. Grades of the mineral suitable for crucibles are also used in the manufacture of retorts for the recovery of secondary zinc and for graphite nozzles and stoppers. The so-called amorphous graphite actually possesses a very fine scaly structure, though its appearance may resemble that of a dull grey flour. In many of its applications natural graphite has to face the competition both of 'retort graphite', a product of gas retorts, and of a product made by roasting mixtures of anthracite or coke with smaller quantities of sawdust and quartz in special electric furnaces as at the Niagara Falls. Graphite, either alone or mixed with carborundum, is an important material in the construction of some types of electrical furnaces, while electrodes made from it are in common use in the electric smelting of many metals, in their remelting and refining, as well as in various electro-chemical industries, such as the production of chlorine by the electrolysis of sodium chloride. Its high electrical conductivity is also responsible for its appearance in dynamo and motor brushes as well as in dry batteries. The lower grades find their main outlets as facings for foundry moulds, to prevent the adherence of castings; as lubricants, either alone or with water, greases and oils, sometimes in a colloidal form; in paints for the protection of metallic surfaces from rust and other corrosive agencies; as stove and other polishes and as 'lead' pencils. Pure graphite has found a new use in the construction of slow neutron reactors, in which several hundred tons of it may be required as well as tens of tons of uranium metal, for a single installation. The first nuclear reactor built in Great Britain at the Harwell Atomic Research Station gained its name of 'Gleep' as a contraction of Graphite Low Energy Experimental Pile. The graphite acts as a 'slower-down' or moderator of the action of neutrons, and in so doing increases the probability of their producing the desired fissions in uranium 235.

Other examples of the uses of carbon as a refractory material, though not concerned with natural graphite, may be mentioned here, for the carbon hearths of blast furnaces operating on acid slags to produce pig iron recall in some respects the graphite crucibles of the steel-maker. Carbon bricks, blocks and shapes for such purposes are made from pastes of powdered, dried, hard coke of low ash content, and moisture-free coke oven tar. Sometimes these linings are of a monolithic character constructed by ramming coke-tar mixtures *in situ*. A striking feature of German practice with carbon block hearths is their extremely long lives. Again, in the direct electro-thermal reduction of kaolin and alumina to form aluminium-silicon alloys, the furnace bottoms are made of carbon blocks.

In the Indian Customs Returns graphite appears under the heading 'Paints and Colours' and again separately as 'Graphite Crucibles', though it doubtless enters into the constitution of many other imported goods. These returns show that though the average annual tonnage of imported graphite fell from 621 tons in the period 1929-33 to 365 tons for the three years ending 1946, the value having increased in the meantime from Rs 248 to Rs 573 per ton; by 1950 the imports had risen again to 667 tons. The importation of graphite crucibles is also increasing, and in 1950 totalled 214 tons, which, with the 667 tons of graphite itself, had a total value of Rs 9,00,000. India's requirements of graphite today are of the order of 2,000 tons per annum and are likely to grow.

It may well be asked why India should spend large sums every year on imported graphite and finished graphite products, when from her own abundant resources she might satisfy her own needs and perhaps compete in the raw graphite markets of the world which at present demand about 250,000 tons of the natural mineral annually. The answer may be given in the words of B. C. Gupta, who wrote in 1949: 'Graphite mining in India stands in need of radical improvement in most of its operational details.' At present most of these are primitive in the extreme, while ore-dressing, mechanical contrivances to clean, grade, and concentrate their products for the markets are little better. Thus there is much waste, and while the discriminating buyer cannot rely on regular supplies of standardized grades, the exploitation of the leaner deposits remains unprofitable. The authors of the Panel Report on Refractories had good reason to conclude that 'more use could be made of Indian graphite if it could be obtained in a pure condition'. These matters have already received some consideration, and flow sheets of beneficiation plants suitable for Indian conditions have been devised and published by N. C. Nandi, and, again, by P. I. A. Narayanan and H. H. Robottom, while B. C. Roy has suggested a 'customs' treatment plant, and the erection of a crucible factory to utilize the Sambalpur mineral at a locality on the Raipur-Vizianagram railway. Finally, intensive prospecting is needed in the extreme south where, as Dr D. N. Wadia has insisted, the chances of discovering workable graphite bodies at numerous centres, similar to those which yield the flake graphites of Ceylon, cannot be ruled out.

CHAPTER XI

MINERAL COLOURS AND ABRASIVES

THE MINERAL COLOURS

THE mineral colours may be divided into three groups as follows: (1) natural mineral pigments, (2) pigments made from ores or ore residues, and (3) chemically manufactured inorganic pigments. The first group includes the ochres, oxides, siennas, umbers and ground slate and shale. In the second are the burnt siennas and umbers, zinc oxide and the red oxides made from roasted pyrites. The last group includes a very large number of colours such as white lead, titanium white, lithopone, chrome yellow, ultramarine and the various shades of red oxides made from ferrous sulphate, recovered from waste pickling liquors of the galvanizing process of iron. Many mineral substances are consumed in the paint industry and among them may be mentioned barytes, asbestos, graphite, gypsum, magnesite, mica, silica, talc, kaolin and clays of various kinds, but here we are concerned only with the members of the first group of the classification.

OCHRES AND OXIDES

The yellow ochres all contain hydrated ferric oxides as their colouring principle, mixed with varying quantities of impurities in the form of clay or fine sand. With decreasing iron content they grade into the siennas, which may also contain a little manganese; with increasing manganese content the ochres shade into the brown and dark brown umbers. The natural soft red earths, both ochres and oxides, owe their value to the presence of ferric oxide, and it is recalled that the original 'Indian Red' of commerce was a bright red oxide with a purplish tint which came from Ormuz Island in the Persian Gulf.

The abundant occurrences of iron ores and laterites in India lead to the presence of ochres and oxides in very numerous localities, and it would be impossible within reasonable limits, even if full information were available, to enumerate all the localities where the inhabitants obtain these natural pigments, generically called *genu*, which are used in the decoration of houses and temples and for many other purposes as well. For example, in south India, pastes made of mixtures of finely ground red oxide of iron and tamarind seed powder (starch) are widely used as protective coatings of brass and copper utensils.

The annual production of ochres and oxides in India, so far as it appears in official statistics, which relate to the large quantities taken from leased areas for industrial uses rather than the small collections from innumerable localities for domestic purposes, now averages about 10,500 tons per annum. The total tonnage so recorded from 1906 to the end of 1949 is approximately 255,000 tons, and of this amount 47·5 per cent has been supplied from deposits in Vindhya Pradesh and 27·7 per cent from those of Madhya Pradesh: up to the early years of the 1930-40 decade, the former state of Gwalior, in Madhya Bharat, followed in the third place with 8 or 9 per cent of the total, but of late years output from Andhra has become increasingly important surpassing that of both Gwalior and Madhya Pradesh. The percentages of the total of 53,167 tons for the quinquennium ending 1948 were as follows:—Vindhya Pradesh 50·8, Madras (including Andhra) 28·9, Madhya Pradesh 11·3, Rajasthan 6·4, Madhya Bharat 2·4, with insignificant tonnages from the Eastern States Agency, Orissa, Mysore and Kashmir. As regards Pakistan, a few hundred tons were forthcoming from Sind in the 1934-43 decade. Burma does not appear in the returns after 1919.

The ochres of Vindhya Pradesh come mainly from Panna, Sohawal, Nagod, Kothi and other districts, where they often occur in association with ferruginous laterites. The well-known ochre mines of Gwalior, in Madhya Bharat, are situated at Behat, in the Gird district, while excellent yellow and red ochres are also worked near Samaria; at Barouli, near Amarpur, as well as on Naro Hill, 6 miles east of Sutna, in Rewa. Of many occurrences in Madhya Pradesh, the soft, micaceous haematites of Jauli, in Jabalpur, were worked extensively in past times, came under European exploitation in 1870, and still meet the demands of local paint works. Similar deposits are known near Gogra, and the yellow ochres of Jhalwara, also in the Jabalpur district, have been marketed since 1937. Quarries at Bhedaghat, on the Narmada river, yield red oxides. Other producing districts include Chanda, Drug and Hoshangabad. High-grade red ochre, containing 53 per cent of iron and 8 per cent of silica, has been reported from Raima, in Surguja, Madhya Pradesh.

Orissa, like most other large regions of the Peninsula, has many recorded deposits of ochreous earths in the Cuttack, Puri, Ganjam, Sambalpur and Koraput districts, but with the exception of those of Sarayi, Moganda and Geruputtu, in Koraput, and possibly others in Cuttack, their colour standard is too poor or their extent too limited for profitable working. Wide areas, however, still await detailed geological examination and better deposits may yet be found. The ochres scattered through what were formerly the territories of the Eastern States Agency are also, for the most part, of inferior grades, fit only for local uses in colour-washing houses and temples, or as temporary dyes for clothes.

According to K. K. Dutta, however, better-quality red ochre is available in large quantities at Khara and Dongaria of Kawardha in Madhya Pradesh.

In Bihar, on the whole, conditions are much the same. 'Admittedly,' wrote J. A. Dunn, 'a large proportion of the deposits of ochre scattered throughout the province are of poor quality, but it cannot be taken for granted that additional ones of suitable material will not be found.' Ochres from extensive beds on the Kaimur plateau, at Madpa, were at one time transported for sale to Patna and Banaras. A good purplish clay is found at Kubasa and other places in the Ranchi district, along the edge of the Dalma lava flows, and extends eastwards into Manbhum, where there are also ochre quarries at Barha Chatarma, not far from Barabhum. Deposits associated with the lavas and tuffs of the Iron Ore Series in south Singhbhum, as well as the micaceous haematites of the Porhat, are worthy of further investigation. It is also possible that the deep black, soft and easily powdered, carbonaceous phyllites of south Ranchi and Singhbhum may be useful as black pigments. Yellow ochre is won on a small scale from surface workings near Nalhati, in the Birbhum district of West Bengal, while both it and the red variety are recorded from the Midnapore district.

There are many references in the literature to the ochres and oxides of Madras and Andhra which are known from the Guntur, East and West Godavari, Kurnool, Visakhapatnam, North Arcot, and Tiruchirapalli (including Pudukkottai) districts. From the quarries of Malkapuram, in the Dhone taluk of Kurnool, red oxide with over 91.5 per cent of ferric oxide is marketed in both the lump and powdered form. Similar oxide is also won from quarries and surface workings at Dwarka Thirumala and Kummarguddem Agraharam, in the Ellore taluk of West Godavari. H. F. Blanford drew attention to a bed of impure yellow ochre in the Cuddalore Sandstones, at Trivandipuram, in Tiruchirapalli, which when ground and levigated yielded a very good pigment, while a clay at Terany, after similar treatment, gave a deep red product. Red ochre and oxides are abundant in Sandur taluk, now a part of Mysore. 'Along the western base of the Ramadrag section of the Sandur hill group,' wrote R. Bruce Foote, 'a vast quantity of intensely red, earthy haematite lies thickly scattered over the great talus. This also seems to be a very pure mineral and would yield a splendid pigment for the mere trouble of collecting and grinding it.' Semi-ochreous masses, from weathered schists and traps of Dharwar age in the same region, are used to some extent as colour washes for house painting; the commoner colours being dull orange and drab, but purplish-grey and lilac are met with, as well as red tints ranging from pale pink to deep red. Red oxide with the unusually high ferric oxide content of 99.8 per cent occurs near Papinyakanahalli, in Bellary. Ochres of many shades of

yellow, red and brown (some of which probably belong to the umber group) occur with iron and manganese ores and limestones in the Chitaldrug and Tumkur districts of Mysore, and find their way into the local paint works, particularly for brown and chocolate pigments. A soft, graphitic rock is also utilized in the manufacture of grey paint.

Ochres and boles (highly ferruginous varieties of lithomarge) of various shades suitable for pigments are common in areas occupied by magnetite-haematite schists and laterite in Hyderabad, and in the Kushtagi area of Raichur are used locally for reddish, chocolate, purple and yellow colour washes. Both red and yellow ochres are found about Pirampalli, Yelchal, Timmareddipalli and Ekmamidi, while ochreous shales underlie Deccan Trap in the western part of the Andola taluk.

The red, ferruginous boles associated with the Deccan Trap in Bombay and Saurashtra have been successfully utilized in the manufacture of red paint. Very large quantities of red ochre exist in the Jurassic rocks near Rajpur, in Jhalawad, Saurashtra, according to C. Karunakaran. Yellow ochres are quarried at Ran and red varieties at Modpur, Matli and Pithasia, in Nawanganar. The quarries of Aditania, Bharwada and Bakharla, in the Porbandar district, where work was commenced about 1932, have produced red and yellow ochres and siennas since then. Dhrangadhra has its own deposits near Baisahebgarh and Ravlivada. In Kutch, mineral pigments are obtained from Cretaceous rocks at Lakhpat and Bhing, while the red and yellow ochres of Padvania, in Rajpipla, Bombay, have been worked for many years.

The deposits of red, yellow and purple ochres of Rajasthan tend to be small and pockety and are exploited by open cuts or shallow pits. They are usually associated with iron ores and ferruginous breccias in the rocks of the Alwar Series, or the Aravalli Limestones, or, again, at the junction of the Jhiri Shales and Upper Rewa Sandstones, as in Bundi. They are in considerable local demand for decorating houses and pottery and have been worked in Alwar, Jaipur, Karauli, Mewar and Jaisalmer, particularly at Nagar Kantha and Devikot in the last-named district.

As might be expected, north-western India and Western Pakistan have but poor supplies, though small deposits of both red and yellow ochres have been reported from Chitral; from Middle Jurassic rocks near Paikhel, in Mianwali, and in larger quantities from Danksa in the Kangra valley. Dr D. N. Wadia mentions pockets of fine, yellow, brown and umber earths in the Salkala Slates, associated with the graphite of Reshian, in the Uri *tahsil* of Kashmir. Further to the east are the ochre beds described by C. S. Middlemiss, where upwards of 200,000 tons of good-quality material, ranging from pale yellow through Indian yellow and Venetian red to deep browns, are believed to be available.

Burma possesses a yellow ochre deposit with a maximum thickness of 30 feet at Panpe, in the Myingyan district, and red ochres are occasionally associated with the laterites of Pegu.

The first paint factory in India is said to have been established in Calcutta in 1902 and for many years the extraction and preparation of the mineral pigments, which are regularly quoted in both lump and powdered form on the Calcutta and other markets, has been carried on. Before the last war large quantities of red oxides of Persian origin, bright yellow ochres and burnt siennas and umbers, were brought into the country from abroad, though the curtailment of such imports over the years of hostilities gave great impetus to the home trade, and resulted in the more extensive use of both red and yellow ochres of Indian origin in the manufacture of paints of various kinds. In a very short time small paint works were started all over the country, local war-time demands were met and the surplus dispatched to China, Malaya, Burma and Australia. In addition to such products as camouflage and ammunition paints, special types of protective varnishes were developed, and, as late as 1950, the number of paint works still in existence was over 125. The market was then overstocked and the production in that year was only 28,000 tons against an installed capacity of 60,000 tons.

It has been stated that while some Indian earth pigments are of very fine quality, with strong, bright colours, the majority of those marketed at the present time are not suitable for first-class paints, owing to their weaker staining powers, and further, that the grades of the raw materials available leave much to be desired owing to lack of proper grinding equipment. These are defects which it is within the power of the producers to remedy, and which must be overcome if the home products are to compete successfully, not only with imported materials in normal times but also with Indian-made synthetic chemical pigments.

There was a time when India supplied large amounts of excellent yellow ochres to the paint trade in the United Kingdom, and amongst the very many deposits now known it is not unreasonable to expect others of the same grade, and uniform enough to supply all her own needs. Prospectors should bear in mind that strong staining power, brightness of tint, fineness of texture and freedom from grit are all factors which determine price and that refining by elutriation followed by drying will often improve both iron content and colour.

The better grades of the brown earths of the raw umber and sienna types are comparatively valuable products. Low-grade kinds are known to occur in the Madhya Pradesh, Mysore, Bombay and elsewhere, but the Paint Federation of India has stated that 'the mines have never been developed to ascertain whether suitable materials can be produced'. More research is also needed on the green earths (*terre verte* or celadonite) often found in association with

the Deccan Traps, for although their tinting power is low, they are used in other lands as bases in the preparation of lake pigments and more particularly for the chrome and zinc greens.

The imports of paint and paint materials into India still continue at far too high a rate considering her own great resources, not only of the natural pigments but also of other mineral substances used by the paint-maker such as barytes, bauxite, gypsum, whiting, kaolin, mica, etc., resources which are vastly superior to those of many countries from which her imports are derived. Though it is outside the province of the economic geologist, the reader may also be reminded of India's position as the world's largest producer of linseed oil and lac, which are also essential materials in the paint and varnish trades, so that, as far as basic raw materials go, the country is in a particularly advantageous position. For the five years ending 1938, India imported an annual average of 16,410 tons of paints and colours, valued at Rs 74,48,294, but her total imports of paints and painters' materials including paints and colours, turpentine, varnish, etc., but excluding linseed oil, reached an average annual value of Rs 97,39,458. Imports naturally diminished during the war period, but by 1946 the corresponding figures were 7,175 tons, Rs 1,13,12,306 and Rs 1,35,48,390. Students of this subject agree that India should be an exporter of such products for sale in the markets of the world rather than a buyer of them from other countries.

BARYTES

Barytes, the sulphate of barium, BaSO_4 , with 65.7 per cent of barium oxide, is a heavy, white mineral and the most abundant of the natural compounds of barium, the only other of commercial importance being the carbonate, witherite, BaCO_3 , a comparatively rare mineral not yet recognized in India, Pakistan or Burma. The importance of barytes is apparent from the fact that the average annual world production for the period 1936-8 was approximately one million tons, of which Germany produced 42 per cent, the United States of America 25 per cent, the Soviet Union perhaps 12 per cent and the United Kingdom about 8 per cent. By 1944, the annual output in the United States alone had increased to over half a million tons.

From the commencement of mining operations in India in 1918, until the end of 1949, 295,623 tons of barytes had been extracted, and almost 92 per cent of this came from Andhra, about 7 per cent from Rajasthan, and smaller amounts from Madhya Pradesh, Kashmir, Vindhya Pradesh and Manbhum, in Bihar. In Andhra, barytes extraction started at Betamcherla, in the Kurnool district, in 1918, and has continued uninterruptedly since that time, a total of 58,290 tons, valued at Rs 6,72,700, having been won up to the end of 1949. The mineral was produced in the Pulivendla taluk

of Cuddapah in 1931 and in Anantapur in the same year. Operations commenced in the former in 1932 and have continued up to date, with the removal of 134,816 tons valued at Rs 15,84,300, up to the end of 1949. Large-scale mining started in Anantapur in 1940, the district having an output of 77,014 tons, valued at Rs 7,28,500, up to the end of 1949.

Systematic geological investigation by A. L. Coulson, in 1932, led to the discovery of 60 barytes localities, of which only 5 had been previously known; 13 of these were in Cuddapah, 11 in Anantapur, and 36 in Kurnool. Later accounts of them have been given by Dr M. S. Krishnan, M. S. Venkatram and M. S. Balasundaram. Most of the occurrences are either in replacement or fissure veins in the Vempalle (Vaimpalli) Limestones, or in the intrusive dolerite and basalt sills, often referred to as 'traps', associated with them. The Vempalle Limestones and slates form the upper part of the Papaghni Series of the Cuddapah System, and in them are also found the chrysotile asbestos deposits of Brahmanapalle. Very large quantities of barytes are believed to be available in a vein at Kottapalle, in the Pulivendla taluk of Cuddapah, and there are several others, mostly in trap but sometimes in limestone, near the same village. In the same taluk there are also quarries in operation at Gondipalle, Ippatla, Kondapuram (where there is a pulverizing plant), Nandipalle, Tallapalli, Velamvaripalli (where the working has reached a depth of 40 feet) and at Vemula and its surroundings. The Badvei taluk of the same district has quarries at Chennakesavapuram and Mamillapalli; the Cuddapah taluk at Kothur, 23 miles from the headquarters of the district, and the Kamalapuram taluk at Kamalapuram, Nandimandalam, Rajupalem and Thangedupalle. From most of these workings the mineral is marketed in the crude, lump form; at a few of them it is ground to powder and sold in three or four grades, including snow-white, white (A & B) and off-colour. In the Anantapur district the leading localities are near Nerijamipalle and Muttsukota, in the Tadpatri taluk, where all the veins are in limestone. Most of the production of the district has come from the former neighbourhood, where one vein, of several, is from 3 to 11 feet thick and has been traced for over half a mile. Quarries are also worked at Boppepalli and Madugupalli. The Kurnool barytes comes from Balapalapalle, near Betamcherla, Hussainpuram, Ramapuram, Yerraguntla and other places, all of which are in the Dhone taluk. Another deposit has been found at Janapalacheruvu, in the Cumbum taluk. The mineral is also known to occur near Naravada and other localities, in the Nellore district of Andhra. The barium solutions are believed to have been derived from the igneous magma responsible for the trap sills in the local Cuddapah rocks, the barytes itself having been precipitated from them by other solutions containing sulphuric acid. The latter were either another derivative of the same magma, or,

as seems more likely in the majority of cases, were themselves produced by the leaching of sulphur-bearing minerals originally present in the Vempalle Limestone.

Barytes has been won in Alwar, Rajasthan, since 1921, the total output to the end of 1949 being 21,611 tons, with a maximum of 2,948 tons in 1929. Jaipur yielded a further 200 tons between 1936 and 1945, and Bharatpur 286 tons between 1943 and 1945. The chief deposits are at Sampuri, Bhagat Ka Bas, Bhakera and Rampur, in Alwar, and they take the form of fissure veins in the less compacted members of the Alwar Quartzites, themselves a part of the Delhi System.

Many other occurrences have been described, and, with one exception, they all indicate that barytes is a mineral of aqueous origin. It is found as concretions in the Belemnite Shales of Kalat and Las Bela, and on the lower scarps of the Pab Range, near Pabni Chauki, two days' journey from Karachi; as great lenticles up to 7 or even 10 feet in width, in an acid dyke cutting through volcanic rocks, 5 miles from the Lower Miri camp, Koh-i-Sultan, in the Chagai district of Pakistan. It is frequently formed by the replacement of other rocks, as at Kolpotka, in Singhbhum, Bihar; accompanying the ores of copper as a vein filling, as at Sleemanabad, Madhya Pradesh, or the ores of lead, as at Silwai and Bogabera, in the Ranchi district, or at Malthol, in Manbhum, Bihar, or, again, in the Mawson State of the Southern Shan States, Burma. At the Bawdwin Mines, in the Northern Shan States, it occurs in late-formed veins alone with no other metallic minerals. Near Surajpur and Bherano, in the Tikamgarh district of Vindhya Pradesh, greyish barytes constitutes 30 to 45 per cent of the filling of quartz veins, up to 2½ feet in thickness, traversing Bundelkhand Gneiss, and associated with small amounts of chalcopyrite, according to T. C. Bagchi. The network of quartz-barytes veins crossing porphyritic gneiss near Alangayam, in the Salem district of Madras, was regarded by Sir Thomas Holland as an original magmatic segregation, but this view has proved unacceptable to other authorities. Barytes veins are also known to occur at Bharra, in Rewa, Vindhya Pradesh; Pipalkote, in Dewas, Madhya Bharat; Bail, Narnaul district, Patiala & East Punjab States Union; Kanti and Tatyana, in Sirmur, Himachal Pradesh; Khanidanda, in Piuthan, Nepal, and in the Great Limestone of the Riasi *tahsil*, Kashmir.

In India, as in other lands, barytes is one of the most widely used minerals in the paint trade, and in the weighting of the muds circulated during the drilling of oil wells by the rotary system. 'Powdered barytes', states the Paint Federation of India, 'possesses a specific gravity and transparency which render it ideal to use as a base for the lake pigments. Its transparency does not interfere with the coloured base from which the lake is manufactured. Its specific gravity and texture impart excellent brushing and levelling properties when incorporated in a paint medium. Its use is not

confined to lake manufacture as it forms the pigmentation basis for at least 50 per cent of the paint trade's manufactured products.' Pure, powdered barytes is snow-white in colour; the lower grades usually have a brown or pink tint, but are still suitable for use in coloured paints and are so employed in very large quantities. Great amounts of barytes are also consumed in the manufacture of lithopone, a chemical product consisting of about 70 per cent of barium sulphate and 30 per cent of zinc sulphide. It is a white pigment, inert, non-poisonous and generally a good paint for many indoor purposes, which is often substituted for the more opaque lead pigments as these are toxic and liable to be discoloured by hydrogen sulphide, often present in the air of towns. Lithopone is also used as a filler for many manufactured products. Chemically pure, precipitated barium sulphate is known as 'permanent white' or '*blanc fixe*', and replaces the pulverized natural mineral in superior-quality paints, enamels and lacquers, besides serving as a base for coal-tar dyestuffs and as a coating for some superior grades of paper. Apart from the paint industry, powdered barytes in its capacity as a filling agent imparts both weight and volume to a whole range of manufactures, including rubber, textiles, paper, cardboard, leather, oilcloth, linoleum, asbestos, plastics and many other goods. It serves the ceramic industry in glazing and enamelling and the glass-maker as a fluxing ingredient and a constituent in some special types of his wares. Many barium compounds are made on a large scale: amongst others are the peroxide, used in the manufacture of hydrogen peroxide; the nitrate, in pyrotechny, green flares and explosives; the oxide and carbonate, in the case-hardening of steel; the chloride and hydroxide, in the purification of beet sugar and in chemical analysis, the former for the detection and estimation of sulphates, the latter for the titration of weak acids in volumetric work; and the titanate in ultra-high permittivity, electrical condensers.

Barium itself is a soft, silvery white metal which melts at 850° C. It is very reactive and greatly resembles metallic calcium in its general behaviour. Available on a commercial scale in both Canada and the United States of America, it forms alloys with aluminium, magnesium, lead, nickel and other metals, but as yet has few significant uses, being mainly employed as a 'getter' for electronic vacuum equipment. It has another outlet in the preparation of some bearing alloys and appears to have possibilities as a deoxidant for high-conductivity copper.

The average annual production of barytes in India rose from approximately 7,600 tons, valued at Rs 52,970, for the five years 1934-8, to 14,300 tons, valued at Rs 86,795, for the corresponding period 1939-43. It increased again in the five years ending 1948 to 23,300 tons and Rs 3,32,894: thus, in the 15 years concerned the annual average tonnage was more than trebled. Over the same period the pit's-mouth value has doubled, from about Rs 7 to

Rs 14 per ton, while the price of lump, off-colour, Andhra barytes on the Calcutta market advanced to Rs 50 per ton and that of the lump, pure white variety to Rs 120 per ton. Some years ago India imported between 4,000 and 5,000 tons of barytes per annum, but over the past decade these imports have dwindled into insignificance as production has increased and internal demand has grown. Indeed, the major portion of the present output is exported, the average for the two years 1947 and 1948 being 15,500 tons valued at Rs 18,07,060. In 1949, 15,822 tons, valued at Rs 17,81,761, were shipped abroad.

To be acceptable to either the paint or the petroleum industries, it is essential that the mineral should be very finely powdered and the product must contain at least 96 per cent of barium sulphate. Paint manufacturers specify a minimum of 1 per cent ferric oxide in crude barytes, and exact penalties for every 0.1 per cent Fe_2O_3 above this amount; further, the residual matter on a 240 B.S.S. sieve must not exceed 0.4 per cent. The processing of barytes for the market is consequently one demanding very close control, if uniformity in size and freedom from iron compounds and other injurious substances is to be ensured. This is again reflected in the price of the finished products: when pure white, lump barytes was selling on the Calcutta market at Rs 120 per ton, standard quality, ground to pass 300-mesh, was sold at Rs 240 per ton.

It has been stated that if careful mining is not resorted to the existing supplies of white barytes will be quickly exhausted in Andhra, and that so far as the Cuddapah deposits are concerned, this quality in any case does not exceed 5 to 10 per cent of the total mineral won. For the orderly development of the Indian industry, therefore, it is important to investigate the problem of producing better-quality products from the tinted, off-colour varieties of barytes.

ABRASIVES

The natural abrasives include bort and carbonado, both of which are varieties of the diamond, corundum, emery, garnet and quartz in their order of hardness. In cutting power the diamond reigns supreme, indispensable for many industrial purposes and unsurpassed by any other substance either natural or artificial. The efficiency of an abrasive depends not only on its hardness and toughness but also on its ability to develop and maintain a proper angularity, even in its smallest particles. It is largely for this reason that corundum has not been displaced entirely by the products of the electric furnace, such as carborundum, the silicide of carbon; synthetic alumina, known under a great variety of trade names; and norbrite, the carbide of boron. Emery, a rock composed of granular corundum and magnetite, familiar in the form of emery paper, cloth and wheels, has not been found in India, Pakistan or Burma, and comes mainly from the Grecian island of

Naxos and from Asiatic Turkey. Garnet, at one time almost universally employed in south India by the cutler, stone-mason and others as a substitute for corundum, still has its applications in certain special crafts in which it is preferred to the harder mineral. Quartz, alone, or in one or other of its numerous varieties, or, again, in rarer cases, in combination with some hard silicate, is the basis of the large group of the siliceous abrasives.

CORUNDUM

Corundum is the natural oxide of aluminium, Al_2O_3 , and its clear, coloured varieties form the ruby, sapphire and other precious stones. Second only in hardness to the diamond, its dull, opaque forms are still used in large quantities and, in spite of the competition of the synthetic preparations, are still regarded as essential for many specialized purposes, particularly for the grinding and finishing of optical lenses, plate glass and quartz surfaces, owing to its superior physical properties and crystalline structure. Its name is derived from the Tamil *kurundam* and is proof enough that the mineral became known to Europe from imported Indian specimens, for it has been worked in the country from very early times to supply the needs of the armourer, lapidary and other craftsmen, by whom it was used either alone or formed into various shapes after mixing with lac. These included discs for laps, wheel grindstones, whets, sills, hones and sticks.

Statistics of corundum production in India are admittedly incomplete for they do not include the casual collections made by villagers, probably amounting to considerable quantities in the aggregate, which reach the bazaars of the cities where the lapidary still flourishes. In any case the output is extremely variable. In 1909, 40 tons were produced and in 1913, 446 tons, valued at £2,215, came from Madras, Mysore and Rewa. For the five years ending 1918, the average annual output was 1,226 tons, and from Assam alone over 2,000 tons were exported in 1917, mainly to the United States of America for fine optical grinding. It is not certain, however, that much sillimanite was not included in this quantity. Production ceased in Rewa after 1920, but commenced again in 1941, while in Assam, with the exception of small quantities taken by the local Khasis for their own purposes, as hone stones, operations were suspended for 26 years between 1922 and 1947. From 1922 to 1934, inclusive, a total of 44 tons had been obtained from the Bhandara district of Madhya Pradesh, between 1925 and 1927; 154 tons from the Salem district of Madras, spread over the years 1926 to 1930, and about 36 cwt. from Kashmir where the mineral is a by-product of sapphire mining. Between 1935 and 1939, the Salem district of Madras yielded a further 31 tons, and 2 tons came from Mysore in 1938. In 1941, production was restarted in Rewa, with a total output of 276 tons up to

the end of 1943, and has continued since that time, while Mysore entered the list again with 20 tons in 1943. For the seven years ending 1950, India's total, annual, average production of corundum was 256 tons, divided in the proportion of 118 tons from Rewa and 134 tons from the Hassan district of Mysore with the remainder from the Khasi Hills of Assam.

The massive sillimanite-corundum deposits of Sona Pahar and other localities in the Khasi Hills of Assam are associated with biotite-sillimanite-cordierite-quartz rock and with sillimanite-quartz schists, intruded by veins of granite-gneiss. Further details of the occurrences are given under SILLIMANITE. The total production of corundum from this area while it was worked between the years 1916 and 1921 was 6,645 tons, to which must now be added a further 26 tons obtained in the years 1948, 1949 and 1950.

The corundum quarries in Rewa, Vindhya Pradesh, are known to have supplied the mineral in 1814 and they were probably worked at a much earlier date. The first reference to them in European literature was in 1820; they were described by F. R. Mallet in 1872, and again by J. A. Dunn in 1929. Today there are quarries at Pipra (Pipari) and Karkota, both of which are in the Vedhan *tahsil*. Near these places there is a small hill which contains a 'bed' of massive, fine-grained, grey, purple or pink corundum, associated with sillimanite and hornblende schists, enstatite-bearing rocks and intrusive granite-gneiss of Archaean age. Dunn estimated that there are 400,000 tons of corundum rock in this vicinity, including 100,000 tons of high-grade mineral, as well as 100,000 tons of sillimanite. The recorded output from Rewa in its working periods has been from 1901-2 to 1920-1, 718 tons; from 1941 to 1950, 1,070 tons.

The massive corundum of Pohra, in the Bhandara district of Madhya Pradesh, comes from alluvial deposits derived from a small hill in which quartzites, sillimanite-quartz-muscovite schists and tourmaline rocks occur. According to Dunn, the deposit is unlikely to have a valuable future, though there is a possibility that other small ones may be found on some of the hills in the neighbourhood. Production ceased here in 1927.

Crystalline corundum has a wide distribution in southern India, most commonly in association with basic rocks containing pyroxene as a predominant constituent, together with some member of the spinel group of minerals. At the same time, intrusions of pegmatite often occur in the vicinity of the corundum-bearing rocks. A great number of localities are listed from the Anantapur, Coimbatore, Salem and South Kanara districts. At Papparapatti, in Salem, C. S. Middlemiss found it in lenticles of feldspar, disposed in parallel bands along the strike of a series of foliated pyroxene-granulites. This band of lenticles has been traced by means of surface indications at intervals from Donnakuttahalli, on the Cauvery, to Chintalakuttai, a distance of nearly 40 miles. At

Sithampundi, in the same district, it is a constituent of anorthite-gneisses, while at Palakod, also in Salem, Sivamalai in Coimbatore, and near Uppinangadi in South Kanara, it is found with syenitic rocks. At Palakod the corundum is associated with greenish-black spinel which is won with it and sold as mixed to local lapidaries, recalling the similar mixtures in the waste gem sands of the Ruby Mines of Burma, used by the jade-cutters of Mandalay and of Tengyueh (Yunnan) in their trade. During the last war, black sands consisting largely of magnetite, recovered from stream beds near Polur and Tiruvannamalai, in North Arcot, were marketed as 'magnetite-emery', for polishing rice. Crushed and graded dark-coloured charnockites and magnetite quartzites were also used for the same purpose. A fused, lateritic material from the Shevaroy Hills of Salem, marketed in India under the name of Alirox, probably contains much artificial corundum from its original bauxitic content.

Corundum of various grades and colours has been found at many localities in the Hassan, Bangalore, Kadur, Kolar, Mysore and Tumkur districts of Mysore, where it is usually obtained in the form of broken crystals from the surface soil, having been freed from the underlying rocks during the normal processes of weathering. Ending with the period 1914-18, when an average annual output of 26 tons was derived from the Tumkur, Mysore and Kolar districts, there was no recorded production until 1938, with 2 tons, and then until 1943, with 20 tons. The regular returns from the Hassan district since 1944 have already been given. Of later years the Hassan production has been partly shipped to the United States of America for stock-piling and partly used in making commercial abrasives in Bangalore.

Coated abrasive papers and cloth are now made in India on a fairly extensive scale and precision grinding wheels are also fabricated by one or two firms, but for the most part imported materials are used for these purposes, in small establishments scattered about the country. The Heavy Chemicals Panel reported in 1948 that the annual imports of abrasives were of the value of about Rs 10 lakhs, while the value of the indigenous production was about half this amount.

No account has been taken here of the fractional quantities of corundum, often amounting to only a few pounds in weight, which have appeared regularly in the returns between 1933 and 1943 as coming from the sapphire mines of Kashmir. They are probably impure blue kinds too poor in quality to rank as gems and are perhaps used for special purposes. The mines lie near Sumjam (Sumsam) in the Kishtwar district of Jammu. Small quantities of corundum are also known to have been obtained from Mahbubnagar, Gulbarga and Nalgonda, in Hyderabad.

Most of the world's supply of corundum comes from the north-eastern Transvaal, in South Africa, whence it is shipped as crystals,

crystal fragments and milled concentrates. Production varies greatly in accordance with market demand and in pre-war years reached about 3,000 tons annually, quickly rising to a peak of 7,000 tons in 1942. Crushing and grading are carried out in the importing countries, mainly the United States of America, where coarse grains are used in the manufacture of grinding wheels, sticks and segments, while whole ranges of fine to superfine grades go to the optical trade and into the preparation of corundum papers and cloths. The finest flour grades are said to be shipped all over the world for the finishing processes of spectacle lenses.

Between 1900 and 1921 Canada produced 19,524 tons of corundum from the Raglan and Carlow townships of Renfrew county, Ontario, and this industry was revived again in 1944, with an output of 1,317 tons in 1945. The Canadian mineral occurs as a constituent of a nepheline syenite group of rocks and in places forms as much as 10 per cent of the rock mass, though the average content of the material as milled is between 5 and 6 per cent. This occurrence is mentioned here because it bears a striking resemblance to some of those in southern India, and particularly to the corundum-bearing nepheline syenites of the Sivamalai Series of Coimbatore, Madras. The Canadian corundum occurs chiefly as a component of reddish alkali syenites and of their pegmatitic facies, found in dykes up to 18 feet wide. The precise affinities of the Sivamalai rock to the local nepheline and augite syenites have not yet been worked out, but it certainly is a genetic relative, due to magmatic differentiation. The nepheline syenite is itself mined on a large scale in Canada for use in the glass and pottery trades, as it contains 20 to 30 per cent of alumina as opposed to 17 to 20 per cent in feldspar, while its higher alkali content reduces the temperature of melting. An analysis of the typical Sivamalai nepheline syenite rock by T. L. Walker shows an alumina content of 23.81 per cent and the high alkali content of 14.39 per cent, while the nepheline itself contains 34.32 per cent of alumina and 20.14 per cent of alkalis.

The Transvaal corundum comes from the Zoutpansberg and Pietersberg districts where it occurs in plumasite—a feldspar-corundum rock (which can be matched in southern India) and eluvial deposits derived from it. Most of the deposits are small and widely scattered over an area of some 3,000 square miles. The material is said to be collected by individual diggers and either hand-sorted or processed in a mill at Pietersberg. By means of a rigorous official control, involving Government grading and the prohibition of exports without a certificate of authorization, quality has been maintained, a reputation for reliability established and a regular flow of trade through efficient distribution channels developed. Thus a small but successful mineral industry based not on the activities of large companies, but on the individual work of many small operators, has maintained its position in the world's

trade in spite of the competition of artificial abrasives. Recent inquiries have revealed that there is a market both in the United Kingdom and in America for good, crystalline grades of south Indian types, which compare favourably in every way with the marketed varieties of Transvaal corundum, and perhaps the adoption of some system of collection and control, similar to that in vogue there, but modified to suit local conditions, might revive the Indian industry and enable it to both satisfy the home demand and contribute to the export trade.

GARNET (ABRASIVE)

Red and brown garnets are common in the crystalline rocks of the Indian Peninsula and, when they possess the necessary transparency and are sufficiently free from flaws, are often cut as gem stones. The iron garnets and particularly the variety almandite, $\text{Fe}_3\text{Al}_2(\text{SiO}_4)_3$, are also used as abrasive materials, an application which they owe to their hardness, brittleness and property of fracturing into small, uneven, sharp-edged, angular fragments under pressure. The abrasive properties of garnet have been known to Indian craftsmen for centuries and were utilized widely at one time as a substitute for corundum. After being crushed, classified and prepared, garnets are used as coatings for paper, cloth and discs in the same way as corundum or emery, the finished products reaching the market in very similar forms. Small quantities of superfine garnet powder are used for surfacing plate glass as well as the softer ornamental stones such as serpentine or marble. Garnet papers and cloth are said to be indispensable for finishing purposes in the wood-working and leather trades; they are also used in the final stages of the preparation of rubber and celluloid goods as well as for scrubbing down varnished surfaces and various other purposes, but the demand is a limited one, only capable of absorbing a few thousand tons per annum and, as a consequence, industrial specifications are unusually exacting.

From time to time large quantities of garnet are reported as having been produced, presumably for such abrasive purposes, in the Tirunelveli (Tinnevelly) district of Madras. In 1914, 1,000 tons of garnet sand were so returned; in 1927, 285 tons; in 1928, 480 tons; in 1932, 147 and in 1933, 295 tons, valued at Rs 2,950. Again, in 1937, 330 tons, valued at Rs 1,650, appear in the returns, and the last recorded output from Tirunelveli was 120 tons in 1938. Over the next decade, 1939-49, only 47 tons 12 cwt. appear in the official mineral statistics, and their origin was as follows: 6 tons from the Nellore district of Andhra in 1939; 23 tons from Travancore in 1944; 8 tons from the Kolar district of Mysore in 1947; 10 tons from the Bhagalpur district of Bihar in 1949 and 12 cwt. from Kishangarh, Rajasthan in 1945.

The Tirunelveli garnet came from sands of the Ovari-Navaladi and Kuttankuli areas. Similar sand is also obtained in large quantities from the sea beaches of Travancore, but such fine, water-borne material, with its sharp edges abraded away, is not nearly so valuable as crushed garnet crystals obtained from rock. In south India, apart from the areas already mentioned, the garnetiferous hornblende gneisses of Khondapalle, in the Krishna district, are capable of yielding garnets in quantity, as also are the schists of the mica belt of Nellore, as, for example, at Saidapuram, and the deposits of coarse crystals found by P. K. Ghosh, near Korissa Konda, in the same district. The mineral is also unusually abundant in the gneisses near Kannamangalam, in North Arcot, and to the west of Seven Cairns Hill, 6 miles north of Ootacamund, in the Nilgiris. A garnet-rich rock from Sanyasimalai, in the Shevaroy Hills, is crushed, graded and marketed as 'garnet-emery'. Graded and coated garnet abrasive products are now made in India by Ajax Products Ltd, of Madras, the supplies of the raw mineral being drawn from the mica belt of Nellore.

Garnets up to one inch in diameter are found in large quantities in the surface detritus of hornblende schists near Kuppur, in the Tumkur district of Mysore. In Hyderabad, similar detrital garnets are available in abundance in the south-eastern parts of Yellandu and the northern portions of the Kammamet and Madira taluks, including the Gobbugurti and Kannigiri Hills. As long ago as 1880, C. L. Griesbach drew attention to the isolated masses of garnet rock in the vicinity of Gobra Hill, and to the patches of the same material associated with hornblende and micaceous quartz schists between Rampur and Kapaut, Surguja, Madhya Pradesh. According to V. R. R. Khedker, there are quantities of loose, garnet crystals, derived from garnetiferous mica schists, near the 7th milestone of the Itarsi-Betul road, in the same State. Garnets weathered from their mother schists are obtainable in the eastern Singhbhum district of Bihar and from adjoining tracts of Midnapore, in West Bengal, as well as in the Rajmahal Hills. Until recently the mineral was collected by villagers near Malibani, in Singhbhum, and it is obtained from the surface as well as quarried as occasion arises at Jha Jha, in the Monghyr district of Bihar. Near Sarsari, in Ajmer-Merwara, A. M. Heron, in 1924, found upwards of 15 irregular bands of massive, reddish-brown garnet more than one foot in thickness. They occur in banded granulites interbedded with crystalline limestone. The largest band, 6 to 12 feet in width, forms an outcrop 15 feet high in places and can be traced for about 300 yards. Four-fifths of this vein is solid garnet, the remainder being quartz, calcite and country rock. Loose blocks, two or three feet across, of almost pure garnet, are strewn in dozens all along the outcrops of the chief bands. The locality is accessible and only 5 miles from the nearest railway. B. C. Gupta, in 1934, recorded Aravalli schists

thickly studded with garnet crystals from various localities in central Mewar. Those near Pur and Harnai Bari merit attention as they are easily approachable from the railway at Bhilwara.

Most of the world's abrasive garnet is won in the United States of America, where the principal source of supply is in the Adirondack mountains of Warren County, New York. The material is obtained by open-cast mining, milled and concentrated by heavy-medium separation. For many years the United States production was between 4,000 and 5,000 tons per annum, but by 1947 it had increased to nearly 8,000 tons. Garnets intended for abrasive purposes should be clean, fresh and free from marked inclusions or decomposition. Those from the Almeria region of Spain used by London abrasive manufacturers some years ago were small, independent, fairly clear crystals about the size of a small pea. Prospectors should note that badly weathered, shattered and impure crystals are not wanted in the trade; moreover, it has been authoritatively stated that in large-scale garnet mining and milling, a recovery of at least 10 per cent from the crude ore is essential if the undertaking is to be profitable.

STAUROLITE

Staurolite is a silicate of aluminium and iron, crystallizing in the orthorhombic system, resembling the minerals of the kyanite group in composition but containing about 16 per cent of ferrous oxide and less than 2 per cent of water, which is retained at a high temperature. A little of the iron may be replaced by magnesium. Its formula is probably $2(\text{Al}_2\text{SiO}_5)\cdot\text{Fe}(\text{OH})_2$. Its hardness is about the same as that of abrasive garnet (7.5), and like it, the mineral is brittle with a subconchoidal to uneven fracture.

Bruce Foote, in his account of the Geological Structure of the East Coast between Ramapatnam and Masulipatam, published in 1880, after referring to the collection and sale of garnet sands in the local bazaars as a substitute for emery, adds that the people 'seem unacquainted with the fact that staurolite, of which an immense quantity is to be had in and near the Chundi Hills of Nellore for the mere trouble of picking it up, is a material of superior hardness to common garnet. Even in the European markets the value of staurolite in that respect appears to be unknown, probably because hitherto untried'. The mica schists of the Chundi Hills are very thickly crowded with staurolite in many places, in others, with masses of pale blue kyanite, or with both minerals mixed up confusedly, as on the Mala Konda which forms the south-western extremity of the hills.

It is known that about 15 tons of staurolite were collected for abrasive purposes at Holenarasipur, in the Hassan district of Mysore, in 1945-6, and, in case of future requirements, some

further localities deserve mention. Detrital staurolite, derived by weathering from its parent mica schists, is available at Pirampalli and Lachaguda in the Yellandu taluk of Hyderabad; east of Tatanagar in Singhbhum, Bihar; and similarly in a belt of mica schists, about one mile wide, east and south-east of Lapsa Buru, and especially near the village of Sini, in Seraikela. A. M. Heron states that the coarsely foliated, crystalline schists of sedimentary origin in western Jaipur, Rajasthan, contain staurolite or large garnets in great quantity.

When clear enough and cut in the proper directions, staurolite furnishes pleochroic gemstones of pleasing appearance.

SILICEOUS ABRASIVES

Grindstones are shaped as a rule from hard, even-grained sandstones, chosen so far as their coarseness is concerned for the type of work to be done by the finished stone. In India, Pakistan and Burma such ideal materials are not always available and so it is found that quartzites, granites, fine-grained quartz schists and similar hard rocks are employed as substitutes. This is not a universal rule, for in some regions there are abundant supplies of excellent stone available, as amongst the Vindhyan sandstones for example, and particularly those of the Shahabad district of Bihar. It was in 1857 that E. Balfour prepared a comprehensive list of 'Materials from the Provinces of the Madras Presidency suited to Grinding, Sharpening and Polishing', an account which the Government of Madras nearly a century ago considered important enough to publish in its own 'Select Records'. In 1941, J. A. Dunn summarized briefly the resources of Bihar, and in 1942 Dr M. R. Sahni's bulletin on 'Abrasives and Grinding Materials' appeared. The abrasive materials available in Orissa are listed in a memoir on the economic geology of the State, by Drs A. K. Dey, B. C. Roy and Messrs A. M. N. Ghosh and G. C. Chatterji, published in 1943, but, for the most part, the notes on the siliceous abrasives which are given here are based on scattered references in Indian geological literature in general.

In the Cuddapah and Kurnool districts of Andhra, coarse, rough feldspathic grits, close-grained, but not as vitreous as an ordinary quartzite, are widely worked for grinding stones. Sandstones of a fine, even-grained texture occur in the Cuddapah and in the Gondwana rocks of Orissa and are quarried near Khandgiri and Nayapali, in the Khurda subdivision of Puri, for grindstones and millstones. Grindstones equal in quality to any imported from abroad are made from the Cuddalore Sandstones of Satras, Chingleput district, Madras. In some parts of Bihar quartzites are quarried for grindstones, and P. N. Bose has related how he saw them being made at Kuliana in Mayurbhanj. The harder

and finer varieties of the Himatnagar sandstones of Idar, in Bombay, would also make good circular stones.

For millstones there is no better material than the hard, tough, coarse, siliceous sandstones of the English 'Millstone Grit', but in Eastern lands, as in the case of grindstones, while the best material may not be available everywhere, more or less efficient substitutes can usually be found. Away from the great alluvial plains, and in those regions where ground cereals form the staple diet of the populace, considerable acumen is displayed in the selection of suitable stones, and small quarries, worked intermittently from time immemorial, betray their provenance.

In Bihar, the coarse arkoses of the Kharakpur Hills at one time supplied a wide region around Monghyr with worked stones, while the fine-grained granites of Chota Nagpur, the traps of the Rajmahal Hills, and the Archæan lavas and dolerite dykes are all suitable and readily obtainable. Among the Gondwana rocks, wherever they occur, the Barakar Grits are widely employed and in many of the coalfields are quarried specially for this purpose. Stones for rice mills are made from the Cuddalore Sandstones of Vriddhachalam and other localities, in the South Arcot district of Madras, while for the pillar sugar-mills of central India, a coarse, porphyritic, granitoid gneiss is favoured. In the Nagpur district of Madhya Pradesh, coarse, gritty, feldspathic sandstones from the Kamthi Beds are utilized, as well as vitreous grits which break with a conchoidal fracture. Hard sandstones of Bijawar age were at one time extensively worked for millstones in Bundelkhand. The Alwar Quartzite is quarried for the same purpose in some parts of Rajasthan, though at Barmer, in Jodhpur, a local, indurated sandstone is used. Strong, tough millstones are made in Kutch from siliceous, ferruginous grits of both Jurassic and sub-Nummulitic Groups and from a very similar rock of Tertiary age. The unusually thick, bedded sandstones of the Kaladgi Series in Bombay are believed to be well suited for the manufacture of large millstones, while for local uses in Idar, mica and quartz schists are taken. Quartz schists and phyllitic quartzites in which the quartz grains are embedded in a slightly softer matrix form part of the Chandpur and Nagthat Series of the Simla Hills, and are worthy of a trial for abrasive purposes, states J. B. Auden.

For sharpening and whetstones, hard, finely granular, quartzose rocks, including silicified wood of Pliocene age in the case of Burma, are the commonest types in general service, but, here again, necessity often compels the use of different materials. The inhabitants of villages in the rocky tracts show shrewd discrimination in such matters, and there is often some particular nearby spot where rock *in situ*, the best that the neighbourhood affords for the purpose, provides a communal sharpening place for both tools and weapons.

Many varieties of rock are used as hones; in Madras fine-grained basalt was employed by cobblers, farriers and saddlers but the cutlers preferred a closely textured yellow sandstone which came from Nellore. Balfour remarks, however, that over a century ago they were being displaced by sills made in Mysore from corundum and lac. In those regions where they are obtainable from Archaean and Cuddapah rocks, in Orissa, or from the Vindhyan formations wherever they happen to occur, the finer-grained quartzites furnish good hones in any quantity. The hard, compact, siliceous limestones and the siliceous slaty shales, such as those of the Kurnool and Cuddapah district of Andhra, make good oilstones, and a hardened grey clay slate from the Guntur district is said to resemble closely the celebrated 'Water of Ayr' stone of Scotland, widely used for sharpening thin-edged tools, such as plane irons and wood chisels. The compact flinty rocks produced in great part by the silicification of volcanic tuffs, of porcelain-like appearance, described by Mallet, Vredenburg, and more recently by Auden, which form the middle stage of the Semri Series of the Lower Vindhyan, along the Son Valley and the Kaimur Plateau, in the Mirzapur district of Uttar Pradesh and Rewa in Vindhya Pradesh, supply materials admirably suited for hones and, as Dr M. R. Sahni has stated, could be more extensively employed than has hitherto been the case. Similar porcellanites can be obtained near Makerchua, Jharnamal, and Khajuria, in the Sambalpur district of Orissa. For finer work still, where very keen, razor edges are required, special stones, such as the Wichita and Arkansas stones of the United States of America, are used in many countries. The latter is a variety of novaculite, and it is not generally known that identical material is to be found just above the Panjal Volcanic Series at Barus and Khunmuh, in Kashmir, in a band 6 to 10 feet thick. Dr D. N. Wadia describes it as a compact, chert-like rock of white or cream colour, intimately associated with crystalline limestone, from which it may have originated by the metasomatic replacement of calcite by silica under solfataric conditions. Varieties of black, flinty jasper, known as Lydian Stone, occur in the rocks of the Kurnool Series, near Nandikotkur in Kurnool district, Andhra. Owing to their colour and hardness they are used by goldsmiths as touchstones in testing the purity of the precious metal, for the colour of the streak so obtained gives a rough indication of the composition of the alloy to the experienced eye.

Rounded pebbles of flint, quartz and tough quartzite are required for tube and conical ball mills of various types, grinding such materials as pottery clays and paint mixtures in which colour contamination from the more usual, steel grinding balls is not permissible; solid blocks of flint, chert or quartzite are also needed for their linings. Dr Sahni has listed 14 localities spread over Bihar, Orissa, Madhya Pradesh, Vindhya Pradesh, Bombay,

Andhra and Uttar Pradesh where such pebbles are obtainable and there are doubtless many more. Large masses of flint occur near the base of the Nummulitic limestones of the Sukkur and Rohri Hills, to the east of Khairpur, in Pakistan. Similar concretions are also found in the Cretaceous Limestones of the Bolan Pass, in Baluchistan. A band of flints, resembling those from the chalk formations of Europe, occurs in clays and shales near Coorhycolum and Senderai, in the Tiruchirapalli district of Madras. In southern Singhbhum there are beds of pure white chert, a mineral which greatly resembles flint, but is perhaps more brittle and splintery, in the Iron Ore Series, particularly near Jamda, and similar material occurs in southern Dhalbhum, feeding the local streams with chert pebbles. The cherts in Chandil, Manbhum, are not so pure, and the mineral is probably available in other parts of Bihar and Orissa, wherever the Iron Ore Series surfaces. Both flint and chert can be found, though not very abundantly, amongst the trap exposures of the Rajmahal Hills. Flint has also been reported from the infra-Triassic limestones of Hazara, Pakistan.

Sands of various grades and sizes are used for sawing and smoothing marble and other ornamental and building stones; for grinding glass; for sand blasting and cleaning metallic surfaces as well as for the preparation of sandpapers. River sands or crushed and cleaned friable sandstones are preferable to the rounded grains of beach sands.

Silica is the base of a great many preparations used in scouring, cleansing, burnishing and polishing operations, ranging from the compact pumice (a honeycombed volcanic glass) used to holystone the decks of ships, or rub down paint work, to the Bath brick and similar substances for domestic cleansing, or the proprietary powders and pastes which impart brilliance to metallic surfaces such as copper and brass. Other preparations now used to impart polished surfaces (claimed to be hard, glass-like and impervious to heat and moisture) to glazed, cellulosed and enamelled surfaces, contain silica in the form of silicones. Diatomite, tripoli and rotten stone all owe their efficacy to silica in some form or other. In the Gangamopteris Beds of the Resin Spur, Khunamuh, near Srinagar, Kashmir, there occurs a volcanic tuff which when pulverized and cleaned is an eminently suitable base for metal polishes, window-cleaning compounds or razor-strop pastes, according to C. S. Middlemiss. Other materials worthy of trial for similar and related purposes include the abrasive silts of Pulivendla, in Cuddapah; the friable, white, chalky clays of Palkur and Nandavaram, in Banganapalle, and Chinna Malkapuram, in Kurnool, Andhra, as well as the non-plastic, white clays to be found about 3 miles south-west of Sitapur, in the Banda district of Uttar Pradesh. A friable tuff, known locally as *bhasma*, occurring in the Ambika river, near Kelkach, Baroda, may be added to the list.

True diatomite has not been found in India, Pakistan or Burma but recent marine muds from banks off the Travancore Coast, near Nerrakal and Alleppey, are rich in the remains of diatoms. Low-grade diatomaceous earths are known to occur on Camorta and Trincutte islands of the Nicobar group.

Sand and emery papers and cloth are now manufactured in both India and Pakistan by firms in Amritsar, Bombay, Calcutta, Kurnool, Lucknow and Rawalpindi.

CHAPTER XII

MINERALS USED IN AGRICULTURE

FERTILIZERS

IN order to maintain agricultural land in productive condition, especially when it has been under cultivation for long periods, it is essential to return to the soil the plant nutrients which the crops themselves have taken from it, or which have been leached away in the course of time by rain-water, a more potent agent in the tropics than in more temperate climates. The principal plant foods are nitrogen, phosphorus and potassium, and a crop of 18 cwt. of wheat removes 35.2 lb. of nitrogen (N), 15.2 lb. of phosphoric acid (P_2O_5) and 9.9 lb. of potash (K_2O) per acre, per annum. Successive harvests and annual monsoons constitute a continuous drain on these vital elements, and unless the losses are made good either by natural processes or by the use of organic or chemical manures, fertility decreases and the land suffers slow exhaustion, reflected in its diminishing returns. Such, unfortunately was the case in undivided India, where yields per acre had been falling before 1939.

Leguminous plants restore nitrogen from the air to the soil through the aid of nitrifying bacteria in their root nodules, in quantities greater than their particular host-plant requires for its own sustenance, but where agricultural conditions or customs do not take advantage of this provision of nature, or permit the addition of sufficient nitrogen in the form of organic manure, the application of nitrogenous fertilizers becomes necessary if plant growth is to be encouraged.

The principal nitrogenous chemical fertilizers are ammonium sulphate (with 20.6 per cent nitrogen), calcium cyanamide (21 per cent N), sodium nitrate (Chile Saltpetre, with 16 per cent N), calcium nitrate (nitrate of lime with 13-15.5 per cent N), ammonium nitrate (with 33 per cent N) and other synthetic compounds such as ammonium phosphate (monoammonium phosphate with 12 per cent N and 62 per cent phosphorus pentoxide, P_2O_5) or diammonium phosphate (with 21 per cent N and 54 per cent P_2O_5), urea (46 per cent N), etc. In 1938-9 the world's output of these nitrogenous fertilizers, reckoned in terms of combined nitrogen, was 2½ million tons of which nearly 75 per cent was 'fixed' from the atmosphere, 17 per cent was a by-product from the coking of coal, while Chilean nitrate provided about 9 per cent of the total.

Ten years later, by 1948-9, the world total had risen to $3\frac{1}{2}$ million tons, excluding the Soviet Union in both cases. The chief function of nitrogen is to promote plant growth and it is especially important for leafy crops and in regions where the soil is subject to leaching. Ammonium sulphate is by far the most important member of this group, providing before the last war about half the total consumption of chemical fertilizer nitrogen.

Phosphorus is a constituent of protoplasm and is necessary for cell division; it is of prime importance when plants are young; it stimulates root development, promotes early ripening of grains and increases their food values. It has been stated that the yield of rice from alluvial land in Burma is roughly proportional to the phosphoric acid content of the soil. As it passes largely into the seed of the plant, soils under cultivation for long periods become deficient in the element. Powdered and burnt bones have been used as phosphatic fertilizers in some countries for centuries, but the action is very slow on account of the poor solubility of the calcium phosphate, $\text{Ca}_3(\text{PO}_4)_2$, which they contain. It was not until 1842 that the Englishman, John Lawes, patented his process for improving the availability of phosphorus by treating bones, or phosphate rock, with sulphuric acid. By this means the insoluble $\text{Ca}_3(\text{PO}_4)_2$ is converted into a soluble form $\text{Ca}(\text{H}_2\text{PO}_4)_2 \cdot \text{H}_2\text{O}$, and the sulphate $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$, the mixture known in the trade as 'superphosphate'. The principal phosphatic chemical fertilizers today are superphosphate (with 14 to 20 per cent P_2O_5); triple superphosphate, made by substituting phosphoric acid for the sulphuric acid used to prepare normal superphosphate (with up to nearly 50 per cent P_2O_5), rock phosphate (with 27 to 40 per cent P_2O_5), basic slag (with 8 to 19 per cent P_2O_5) and ammonium phosphate (with 54 per cent P_2O_5 and 21 per cent N, or 62 per cent P_2O_5 and 12 per cent N). The organic members of the group include bone meal, guano and fish and animal residues. Superphosphate accounted for some 85 per cent of the world's total output of manufactured phosphates in 1948-9, estimated at 5 million tons P_2O_5 , compared with $3\frac{1}{2}$ million tons in 1938. Even before the war the output of phosphate rock, from which most of this is made, had reached 13 million tons per annum. By 1948-9 the world total had risen to 19 million tons, some 80 per cent of which went into superphosphate works. After superphosphate, the second most important phosphatic fertilizer is basic slag, a by-product of the iron and steel industry which is said to provide perhaps one-sixth as much P_2O_5 as does superphosphate. The other forms of phosphatic fertilizers are relatively unimportant.

Potassium is especially useful in the early stages of plant life, as it enables full use to be made of the available nitrogen and, by promoting healthy growth, renders the crops less liable to attacks of fungal and bacterial diseases. The element is mostly retained in the stem and leaves of the plant and returns to the soil if these

parts are not removed for consumption. At the same time, it is stated that potash is often deficient in light, sandy or thin soils, while even in rich soils there may not be sufficient to support heavy crops. Over 90 per cent of the world's total production of potassium salts is used for agricultural purposes: excluding the Soviet Union this amounted to the equivalent of some $2\frac{1}{2}$ million tons of K_2O in 1938, rising to $3\frac{1}{5}$ million tons in 1949. The sulphate, K_2SO_4 , and the chloride, KCl , which in the relatively pure form contain 48 to 52 per cent and 48 to 62 per cent K_2O , respectively, are the chief compounds used as plant foods, but a number of complex salts from the deep-seated, saline, evaporite deposits are also marketed as mined, or with but little refining; their value depending on the amount of the oxide, K_2O , which they contain.

Fertilizers are marketed singly or, more often, as mixed plant foods containing two, or all three, of the essential elements in stated proportions, usually in the form of granules, and when desirable fortified with traces of elements such as boron, copper, cobalt, manganese and zinc, which in recent years have been found advantageous to healthy plant life. In the United States of America, most of the superphosphate used in mixed fertilizers is treated with either anhydrous ammonia, or strong ammonia solutions containing ammonium nitrate or urea. Anhydrous ammonia is increasingly used in the same country for direct application to the land, especially on the larger cotton estates.

In the compilation of these introductory remarks some information has been derived from the Report of the Commonwealth Economic Committee on The Trade in Fertilizers (1950).

SALTPETRE (POTASSIUM NITRATE)

Many years ago, and for quite a lengthy period of time, India possessed a virtual monopoly of the world's supply of nitrates, which are essential for the manufacture of explosives and are at the same time invaluable as agricultural fertilizers. As the natural nitrates are soluble in water, they are only to be found in large quantities under very exceptional circumstances, and India was displaced from her leading position by the exploitation of the vast deposits of sodium nitrate (Chile Saltpetre) occurring in the rainless deserts of Chile. These, in their turn, have had to meet the competition of nitrogen in the form of ammonium sulphate obtained as a product of the carbonization of coal and also of synthetic nitrogen-bearing compounds made from atmospheric nitrogen.

Potassium nitrate, KNO_3 , is formed wherever organic, nitrogenous substances decay in contact with potassium salts, the reaction being brought about by nitrifying bacteria; thus in temperate climates it can be found in the lime and plaster of old buildings, particularly near the ground where sewage effluents have percolated. The so-called 'nitre plantations' of some parts

of Europe in the last century took advantage of the same natural processes: large heaps of manure and animal refuse, interlaid with brushwood, were built up, covered with wood ashes, old lime and similar rubbish of an alkaline nature, turned over occasionally and then allowed to ferment for two or three years when the heaps, on lixiviation with water, gave solutions which on treatment with potash yielded saltpetre.

In some parts of the plains of India and of Pakistan conditions are favourable for the formation of saltpetre, particularly where there is a dense population using wood and cow-dung as fuel, and existing under climatic conditions in which atmospheric temperatures and humidity favour the growth of the essential micro-organisms about the villages. In such situations efflorescences containing saltpetre grow on the surfaces of walls, refuse heaps, the sites of deserted villages and the environs of existing ones. After collection their treatment consists of lixiviation, evaporation, the addition of wood ashes to decompose the calcium nitrate present, and fractional crystallization. The crude saltpetre so obtained varies greatly in composition and is usually refined before export.

At one time the Gangetic districts of Bihar produced as much as 20,000 tons of saltpetre annually from the Muzaffarpur, Saran, Champaran, Darbhanga, Shahabad, Gaya and Monghyr districts, but the industry has declined and now averages annually only 1,714 tons of the refined nitrate, though in 1949 production rose to 6,047 tons, valued at Rs 31,54,792. In Uttar Pradesh the chief producing centres are in the Kanpur, Ghazipur, Allahabad and Banaras districts, where output remained fairly steady at 2,030 tons per annum over the decade ending 1944. Punjab saltpetre comes from the Lahore, Hissar, Multan and Amritsar districts and with a fairly large number of refineries at Hissar, Hansi and other places easily headed the list with an average of 5,333 tons per annum for the decade ending 1944. It is also collected in Patiala, Jhind and Nabha of the Patiala & East Punjab States Union. The manufacture of crude saltpetre was once widespread in the south, especially in the districts of Anantapur, Coimbatore, Guntur, Kurnool, Madurai and Nellore, but today it only forms a part-time occupation of the poorer members of the Uppliar class and is practically confined to the Coimbatore and Madurai districts, where output has become insignificant. In much the same way it has died out in the Ahmedabad district of Bombay. Saltpetre is imported into India from Nepal and is made on a small scale by the Kachins of the Burma-China frontier regions who use it in the manufacture of gunpowder. Crude nitrate-bearing earths are known to occur in the Bughti territory of Baluchistan, and such materials are applied directly to the fields in parts of Bihar and in the Doabs of Pakistan. Twenty years ago the tea gardens of Assam consumed about 700 tons of Indian saltpetre every year, but this has fallen

away to about 200 tons annually for the period 1944-6, owing to the more extended use of imported fertilizers of the same type.

The manufacture of saltpetre in the old days was a monopoly of the East India Company, and the average annual exports during the years 1791 to 1805 amounted to approximately 80,000 tons. For the years 1876 to 1880, the average had fallen to some 21,000 tons, and it declined still further to 19,500 tons at the end of the century. The industry used to respond to the stimulus of war periods, and it is interesting to note that it reached its zenith at the time of the American Civil War, when the value of the exports ranged between £600,000 and £900,000 per annum. In the quinquennium before the first world war, the average annual exports had sunk to 16,440 tons, but the expected revival occurred and the next period of the same length witnessed an increase to 21,740 tons. It was followed by a rapid and continued slump, and for the five years ending 1933 exports averaged only 6,467 tons. Over the next quinquennium, ending 1938, they increased again to an annual average of 8,183 tons, but thereafter, for the first time in its long history, the industry displayed no favourable reaction to war's demands, and exports fell to an average of 6,917 tons during 1939-43, and dropped to an all-time low record over the five years ending 1948, with an average of but 734 tons.

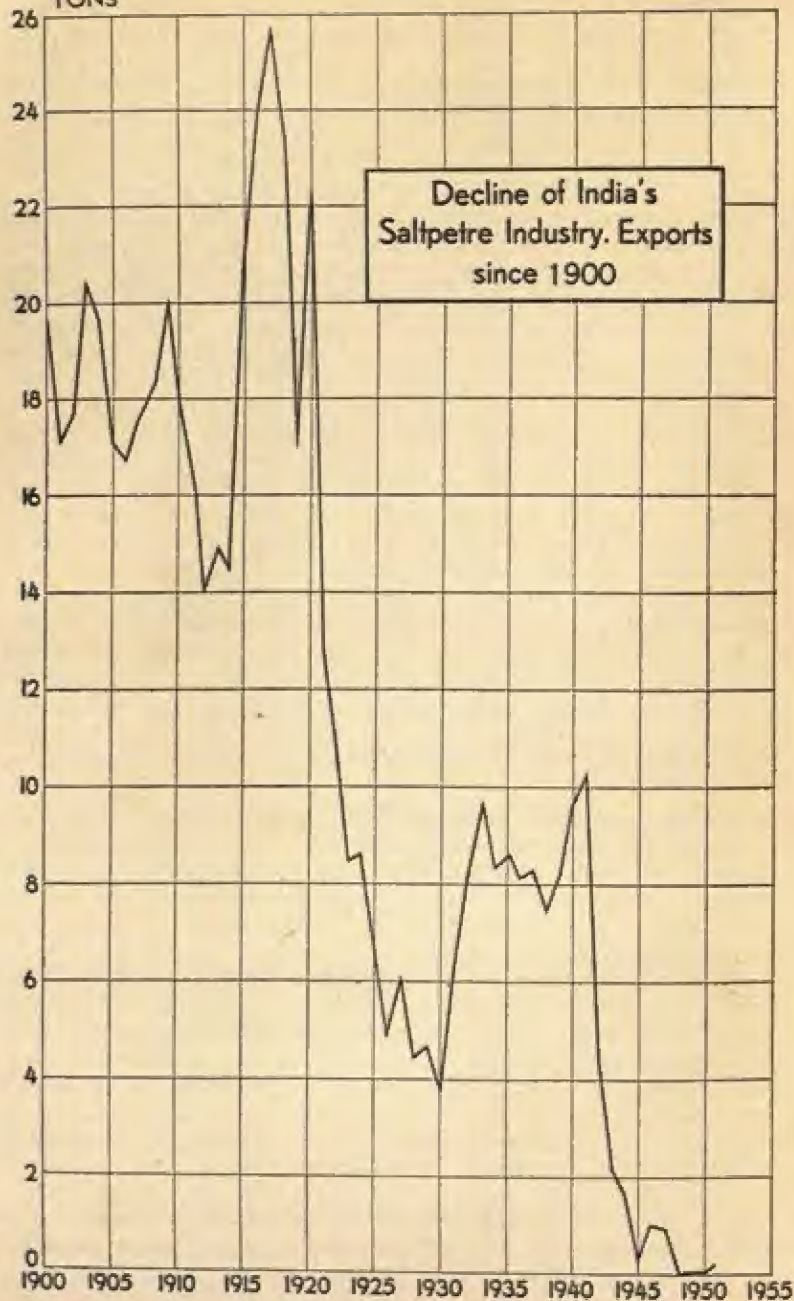
Production figures, such as they are, and they have not always proved reliable, indicate an annual internal surplus of about 2,000 tons, over the decade ending 1943. It can only be hoped that the low export figures for the quinquennium ending 1948 indicate that at long last the value of potassium nitrate in India's own economy has been realized, and that the inconsistency of exporting home-made potassium nitrate, while at the same time importing thousands of tons of other potassium salts from abroad, will soon be ended, for neither India nor Pakistan can afford to part with their potassic or nitrogenous fertilizers. The production figures for 1948 and 1949, which totalled 9,019 tons, valued at Rs 42,86,414, compared with the total exports from India over the same period, amounting to 51 tons, valued at Rs 89,164, seem to show that this is indeed the case.

The total exports of saltpetre between the years 1897 and 1948 were 609,190 tons of a nominal value of £11,077,984. The details given in the table on p. 471 show the destinations to which it was shipped together with their variations in quantities and time over this period. Following the division of India on 15 August 1947, some, though not all, of the producing areas of the Punjab passed into Pakistan, where during the years 1948 and 1949 a total of 7,669 tons was produced.

OTHER POTASSIUM SALTS

Potassium-bearing minerals discovered in the Mayo Mines of the Salt Range by H. Warth, in 1873, were on examination by

THOUSAND
TONS



INDIAN SALTPETRE EXPORTS AND THEIR DESTINATIONS, 1897-1948*

SALTPETRE

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PERIOD	TOTAL TONNAGE	VALUE	UNITED KINGDOM	HONGKONG	UNITED STATES OF AMERICA	MAURITIUS	FRANCE	STRAITS SETTLEMENTS	CEYLON	JAPAN	OTHERS	EXPORTED FROM		
												Calcutta	Bombay	Karachi
1897-8 to 1902-3 ..	114,706	£ 1,575,552	30.7	25.7	24.0	6.3	6.0	2.6	2.0	1.4	1.3	98.5	..	..
1903-4 to 1907-8 ..	89,747	1,326,675	25.0	22.1	32.8	6.3	6.1	2.8	2.8	..	2.1	98.6	..	..
1908-9 to 1912-13..	82,882	1,263,170	19.2	23.7	27.2	12.4	2.9	3.0	7.7	..	3.9	98.4	..	..
1914-18 ..	108,685	2,588,950	76.8	3.7†	7.0	2.3	..	..	4.7	2.4	3.1	78.4	7.6	14.0
1919-23 ..	71,338	1,986,352	29.9	15.2	9.2	18.0	..	..	19.5	0.9	7.3	88.4	2.3	9.3
1924-8 ..	30,305	636,105	13.4	10.2	..	9.8	..	3.7	59.9	..	3.0	94.9	4.1	1.0
1929-33 ..	32,335	407,987	29.2	..	..	29.1	..	2.1	33.5	..	6.1	..	..	..
1934-8 ..	40,916	458,062	23.3	..	..	45.4	..	..	14.6	..	16.7	..	..	..
1939-43 ..	34,586	654,178	43.0	..	..	31.8	..	..	9.5	..	15.7‡	..	..	..
1944-8 ..	3,670	180,953	27.9	..	..	27.2	..	..	3.0	..	41.9§	..	..	..
GRAND TOTAL ..	609,190	11,077,984	..	..	..	..	..	..	..	..	..	..	..	..

* Expressed as percentages of the total trade.

† To China.

‡ Includes 1.2 per cent to Australia.

§ Includes 5.5 per cent to Australia.

G. Tschermak and F. R. Mallet proved to consist of mixtures of common salt and magnesium sulphate, or kieserite, $\text{MgSO}_4 \cdot \text{H}_2\text{O}$, with sylvite, potassium chloride, KCl , and langbeinite, a double sulphate of potassium and magnesium, $\text{K}_2\text{SO}_4 \cdot 2\text{MgSO}_4$. Sylvite is an important member of a group of minerals occurring in the great residual saline deposits of Germany, France, Spain, Poland, the Soviet Union and the United States of America; langbeinite also occurs in some of them and is of commercial importance both in the United States and in Poland. Both minerals are typical members of the evaporite group, formed by the desiccation of shallow arms of the sea, or of desert lakes, in earlier geological times. Their commoner associates include carnallite, a hydrated chloride of potassium and magnesium, $\text{KCl} \cdot \text{MgCl}_2 \cdot 6\text{H}_2\text{O}$; kainite, hydrated potassium chloride with magnesium sulphate, $\text{KCl} \cdot \text{MgSO}_4 \cdot 3\text{H}_2\text{O}$, and polyhalite, a hydrated sulphate of potassium, magnesium and calcium, $\text{K}_2\text{SO}_4 \cdot \text{MgSO}_4 \cdot 2\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$.

Warth's discovery, though it only amounted to about half a ton of the mixture, led to the suspicion that larger, economically important occurrences of such minerals might exist in association with the rock-salt deposits of the Salt Range, but this has not proved to be the case, at least in so far as investigations have been carried to the present time. In 1913, W. A. K. Christie found 21 separate places in the Mayo Mines alone, in which potassium-bearing minerals occurred. Many of these were too small to be of any commercial value, while others revealed the existence of three distinct seams which appeared to thin out when followed upwards. The amount of potash, calculated as K_2O , in the visible portion of the uppermost seam was estimated at 3,000 tons, while the percentage of potash in the average samples taken varied from 6.8 to 14.4. Another bed about 6 feet thick was found in the Nurpur mine, and it contained 13.6 per cent K_2O . In addition to the minerals already mentioned, the presence of kainite was recognized at this time. Small-scale operations at Nurpur resulted in the extraction of 268 tons of potash between 1918 and 1920, but they were abandoned in 1921.

Another investigation was conducted by Murray Stuart in 1915-17, including both the Punjab Salt Range occurrences and those of Kohat. He found two distinct seams at the Nurpur mine but added, 'not only do the potash bands vary abruptly in thickness and direction, but they vary throughout their length in the percentage of potassium in them'. Potash was also found in three chambers of the Warcha mine, but these deposits were not regarded as promising. Stuart's conclusions were summarized as follows: 'On the whole the evidence collected during my investigations points to the conclusion that no continuous bed of potash will be found in the Salt Range or in Kohat. The salt is a foliated rock and the potash salts occur in discontinuous lenticles and irregular

foliae. Where the foliation is of the nature of banding, bands of potash may persist for some little distance, but even then they will probably thicken and thin throughout their length. The prospects of obtaining potash in the Salt Range are not therefore promising, and it is not likely to be worked profitably except as a by-product of salt mining.' At the same time it should not be overlooked that the researches of both these observers, the first a chemist and the second a geologist, were restricted to mines officially developed by a Government Department, with the sole object of a profitable recovery of marketable rock salt. The mining engineers responsible for the operations 'have therefore', wrote Christie, 'naturally altered the direction of their workings on striking a seam of marl or impure salt of any considerable thickness and before the underlying strata were exposed. Most of the occurrences of potassium salts are overlaid by marl seams, and the exposures, consequently, are neither frequent nor easily followed out'. In fact, until the whole of the Salt Marl with its associated beds of gypsum and rock salt has been systematically examined by core boring, with all the necessary precautions that the recovery of soluble minerals entails, it is premature to dismiss the possibility of the occurrence of potassium minerals in profitable quantities either in the Salt Range or elsewhere.

In some parts of the world, potassium salts are recovered from lake brines, as in California where they are by-products of borax and magnesium chloride manufacture, or, again, from the saline lakes of Utah, in the United States of America. In Palestine they are won from the waters of the Dead Sea. Somewhat analogous processes are in operation on a small scale in India, for the Pioneer Magnesia Works Ltd market a product containing 70 per cent of potassium chloride, recovered as a by-product of the manufacture of magnesium chloride from the brines of wells at Kharaghoda and Himatnagar, on the Rann of Kutch, while Tata Chemicals Ltd market potassium chloride obtained from the residues of sea brines at Mithapur in the Bombay enclave in Saurashtra. The former concern commenced production in the period 1940-1 and in the ensuing 10 years 1,671 tons had been made.

Indian imports of potassium salts for fertilizers, mainly in the form of the chloride, averaged 5,118 tons per annum, over the decade ending 1938: over the decade ending 1948 the annual average had fallen to 1,528 tons, but by 1949 it had risen again to the neighbourhood of 5,000 tons.

In addition to their uses as fertilizers, and plant life cannot exist without them, potassium salts find many other applications. The metal itself is not made on any extensive scale since for most purposes metallic sodium, which it resembles very closely, can be equally well employed. The hydroxide, caustic potash, is a useful drying agent and absorbent for such gases as carbon dioxide and sulphur dioxide; it is a very strong base employed in the manufacture

of soft soap and as the electrolyte in the nickel-iron storage battery; the chloride finds its chief outlet as a fertilizer; the bromide in photographic preparations and in medicine; the iodide in the same ways and in volumetric chemical analysis. The chief use of the nitrate is in the manufacture of gunpowder and fireworks, in the preservation of meat, in the curing of tobacco and in drugs; of the chlorate in explosives, matches and pharmacy; the chromate and dichromate in tanning and dyeing; the ferricyanide in blue-print paper; the permanganate in antiseptics and the cyanide in the extraction of gold from its ores. Hard glasses and the better qualities of glass for crystal ware, electric light bulbs, X-ray tubes and optical glasses usually contain a high percentage of potash in their alkali content.

PHOSPHATES

It has been known for many years that laterite soils, especially those of the Peninsula and of Burma, which have been devoted to paddy cultivation for generations, are particularly deficient in phosphorus. It is also common knowledge that by the application of superphosphate alone the productivity of such soils can be increased by 30 to 40 per cent, while a combination of superphosphates with organic manures gives even better yields. The best results of all, and this applies to other crops besides rice, are obtainable by the combined application of nitrogen and phosphoric acid in a soluble form. India has a population of nearly 350 million, and 7 workers out of every 10 depend on the land for a livelihood. There are a further 82 million people in Pakistan, where 8 persons out of every 10 also subsist on agriculture. One of the chief obstacles to the betterment of the results of their labours in both countries is the lack of manure, for it is as true today as when Dr Voelcker wrote his treatise on 'The Improvement of Indian Agriculture', that 'Water and manure together, represent in brief the ryot's chief wants'. There is a great disparity of agricultural yields per acre between India and some other countries—600 lb. of wheat and 66 lb. of cotton per acre compared with about 1,000 lb. of wheat and 313 lb. of cotton, for example, in the United States of America, but while the United States cultivates 360 million acres and India 306 million, with a much more intense application of manpower, the former uses, on an area only one-sixth greater, over 13 million tons of fertilizers a year against about a quarter of a million tons used by India. While natural differences of soil fertility do not account for the whole of this dissimilarity, they are undoubtedly responsible for a large part of it. One Inspector-General of Agriculture in India wrote as follows: 'A great deal of land, particularly in the poorer tracts of Peninsular India, is slowly undergoing exhaustion for lack of manuring, yet the deposits of the mineral phosphates which might form the basis of mineral fertilizers remain unworked, and immense quantities of

phosphates and other fertilizers in different forms are exported every year.' In 1953 the final report of the All India Soil Survey Scheme was published by the Indian Council of Agricultural Research. It contains a chapter entitled 'Soils in Relation to Crops' which reveals how widespread and serious the general shortage of plant nutrients really is. Thus the soils of West Bengal, Bihar, Orissa and Madras are described as deficient in both nitrogen and phosphorus. The alluvial soils of the Indo-Gangetic plain, which with those of the coastal areas of the South, including the deltaic tracts, comprise the most important agricultural lands of the country, are stated to be 'deficient in phosphoric acid, nitrogen and humus but not generally in potash and lime'. The response of crops of many kinds in all these and other regions to the scientific application of suitable fertilizers, as described in this valuable report, has been both impressive and remunerative.

Apatite is the primary source of phosphorus in the soil and it is a very widely spread mineral which occurs in small quantities in rocks of all types and ages, but is commonest in the igneous rocks which generally contain about 6 parts per thousand, representing about 0.1 per cent of phosphorus. Apatite is a phosphate of calcium which also contains chlorine or fluorine, or both these elements: two compounds are really included in the species, the first being fluor-apatite, $3\text{Ca}_3\text{P}_2\text{O}_8 \cdot \text{CaF}_2$ and the second chlor-apatite $3\text{Ca}_3\text{P}_2\text{O}_8 \cdot \text{CaCl}_2$ and they both contain when pure about 41 or 42 per cent of P_2O_5 . Altered in the processes of weathering and eventually dissolved by carbonated water, some of the phosphoric acid thus removed is carried by rivers to the sea, where it is largely removed by small living organisms, themselves the food of larger creatures which are eaten in their turn by fish, in whose bodies the phosphorus becomes concentrated. The fish are devoured by gluttonous sea-birds whose droppings constitute guano, which in rainy climates may convert underlying coral reefs and limestones into valuable deposits of phosphate rock. Another portion of the original phosphorus is retained by the soil, to be extracted in the course of time by plants, and from them it passes into the bones of land animals. Apatite is sometimes concentrated into deposits of economic importance such as those now to be described.

In the schists of a zone of country in the Dhalbhum subdivision of Singhbhum, extending over a distance of about 40 miles from the eastern border of Seraikela to Khejurdari and thence into Mayurbhanj, veins and lenses of apatite have been found. The mineral is usually fine-grained and magnetite is associated with it in places, as well as biotite, quartz and chlorite in varying quantities. The veins themselves are associated with, and strike parallel to the copper lodes of the same region; indeed, those best able to judge, such as M. S. Krishnan and J. A. Dunn, regard both as liquations from the soda-granite magma which ascended

along the overthrust zone of this part of Singhbhum. The deposits fall naturally into three well-marked sections, the best being from the Seraikela border to Chandar Buru and especially round Nandup. It also has the advantage of lying nearest to a railway. Mining was carried on for several years in this Nandup area by E. O. Murray, and for the period 1924-8, 14,700 tons of apatite were extracted. The largest group of veins, to the north-west of Chandar Buru, exhibits at one point a width of 60 feet of apatite with schist partings. Another vein at the southern foot of the hill, with a width of up to 10 feet, had been worked over a length of 300 yards. The second section is located around Patharghara, and between this place and Khariatola there are several veins 10 to 20 feet thick, none of which, however, exceeds 200 feet in length. The material here is unusually high in magnetite and the area was leased at one time to the Bengal Iron and Steel Co. Ltd as a source of phosphoric iron ore. The third and southern section stretches from Badia, through Kanyaluka, to Sungri and Khejurdari, where the Great Indian Phosphate Co. Ltd worked during the 1914-18 war. Some of the veins are well developed but are not so persistent as at Nandup. At Sungri in particular, however, they contain high-grade mineral, perhaps the purest of the whole region and composed of a white apatite free from magnetite and chlorite. The total quantity of apatite rock produced from the belt from the commencement of working, in 1918, up to the end of 1938, amounted to about 28,000 tons, and between that year and 1947 a further 3,755 tons were removed. The reserves of apatite-bearing rock in the three areas concerned have been estimated as follows: Nandup, 250,000 tons; Patharghara, 250,000 tons; Badia-Kanyaluka-Sungri, 200,000 tons; a total of 700,000 tons down to a depth of about 200 feet. It is surmised, though not definitely known, that the veins are of lenticular habit, but even if this should prove to be the case, 'there is', in the words of Dr M. S. Krishnan, 'no reason why there might not be similar lenses at depths of several hundred feet in the same mineralized zone'. The apatite rock as mined generally contains 20 to 25 per cent P_2O_5 . P. I. A. Narayanan has shown that the Nandup apatite ore is amenable to concentration by straight flotation and one cleaning operation. From a bulk sample assaying 52.31 tricalcium phosphate $Ca_3(PO_4)_2$ (23.94 per cent P_2O_5) he made a recovery of 94.8 per cent, containing 84.3 per cent tricalcium phosphate. The Sungri ore also yielded excellent results after the electro-magnetic separation of its magnetite.

Apatite occurs as an accessory mineral in the mica-bearing pegmatites of the Hazaribagh district, Bihar, and of the Nellore district, Andhra; in the rocks of the Kodurite Series of Srikakulam district, Andhra; in the mica-peridotites of the Giridih and Raniganj coalfields; in rocks associated with the manganese ore deposits of Narukot, Bombay; and in certain schists of Dungarpur,

Rajasthan. Triplite, a fluor-apatite of iron and manganese, occurs near Singar, Gaya district, Bihar, but it is unlikely that any of these occurrences will provide commercial supplies of phosphates. Monazite, the phosphate of cerium and other rare-earth metals with some thorium silicate, normally contains 26 to 28 per cent of phosphorus pentoxide, P_2O_5 . This should be recoverable in some suitable form as a by-product, now that the processing of monazite has been commenced in India, though the quantity so obtainable will not be large.

So far we have dealt only with deposits in which the apatite is of igneous or of high-temperature origin, and although in almost all the other deposits the phosphorus occurs also in the form of fluor-apatite, or in a series of very closely related minerals derived from it, a sharp distinction must be drawn between the first, or crystalline apatites, and the second, the amorphous rock phosphates, described below. The crystalline forms have very little value for direct application to the land, whereas the amorphous types may be slowly broken down in acid soils and their phosphorus content become available for plant life. This distinction is mentioned here to discourage the well-meaning suggestion that powdered Singbhum apatite rock would make a suitable top dressing for agricultural land in Bengal and Bihar.

In the world as a whole there are few apatite deposits of the crystalline type capable of supplying the mineral in workable quantities, though these do include the great lenses of apatite-nepheline rock of the Kola Peninsula, in northern Russia, which in pre-war years yielded about 2 million tons of the mineral annually. The rock phosphates are by far the largest source of the phosphates of commerce. They may result from the leaching of guano, the accumulated excreta of sea-birds, found in thick beds on oceanic islands such as Nauru, Ocean and Christmas Islands in the Pacific and Indian Oceans, or along desert coasts such as those of Chile and Peru. Percolating phosphoric acid from such materials has, in these cases, converted the underlying limestones into phosphate rock. More important than these, however, are the beds of phosphate rock and layers of phosphatic nodules which occur interstratified with limestones, marls, sandstones and shales in lagunary and marine sedimentary deposits, particularly in the United States of America, Tunisia, French Morocco and many other countries. Residual deposits of high-grade phosphates are sometimes formed by the decomposition of phosphatic dolomites and other rocks containing phosphorus. Some of the deposits of the rock phosphates are of vast extent; in Florida (U.S.A.), for instance, where they are of Tertiary age, they extend in a belt 200 miles long and 20 miles broad, along the western side of the State, and six separate varieties of the rock, with phosphate contents ranging from 68 to 75 per cent, are won.

Both India and Pakistan have representatives of the rock and nodule classes, the latter in the large deposits of Tiruchirapalli, South Arcot and Pondicherry, and the former in the thin bed of phosphate rock which has been traced for over a mile near Mussoorie, in Uttar Pradesh. In the Jhelum district of the Punjab of West Pakistan, phosphatic nodules occur in the shales above the Eocene Coal Measures, particularly around Dandot in the Salt Range.

In the Tiruchirapalli district of Madras, to the north-north-east, east and south-east of Uttattur, the rock Stage of Cenomanian age which bears the name of this town contains irregularly distributed phosphatic nodules over an area of about 12 square miles. The occurrence was investigated by Dr H. Warth in 1893, and again by Dr M. S. Krishnan in 1940: combining the results of both these skilled observers, it appears that on the average there are 28 lb. of nodules per 100 cubic feet of strata, giving a total reserve of over 8 million tons, to a depth of 200 feet. Dr Krishnan, however, considers it doubtful if more than 2 million tons are recoverable economically, though no definite opinion is possible until the costs of large-scale operations are available.

The phosphate deposits of South Arcot and Pondicherry occur in the upper part of the Ariyalur Stage, in a ridge between Tutipattu and Akasampattu. This particular zone is several feet thick, and is part of the spread of Cretaceous rocks occupying an area of some 32 square miles, and belonging entirely to the Ariyalur and Niniyur Stages of Senonian to Danian age. These deposits have not yet been systematically investigated. Analyses of the Uttattur nodules show an average content of about 25 per cent P_2O_5 . The phosphorus-bearing minerals contained in them undoubtedly belong to the insoluble fluor-apatite group and probably include hydroxyapatite, staffelite, dahllite and collophanite. Trials of the powdered nodules on tea and coffee plantations in south India and Ceylon gave disappointing results, especially in comparison with the quicker-acting superphosphate, though this should not have been unexpected. Experiments in the flotation and tabling of the powdered nodules by P. I. A. Narayanan did not give satisfactory results: on the other hand, Dr K. R. Krishnaswami raised the P_2O_5 content from 28 to 36.6 per cent by tabling the calcined product. Further researches are necessary to render these phosphate deposits useful to Indian agriculturists, and the silico-phosphate process, as well as the preparation of fused tricalcium phosphate by defluorinating methods, seem worthy of consideration, as they eliminate the use of sulphuric acid. The recorded production of phosphatic nodules from the Tiruchirapalli district, up to the end of 1950, was approximately 12,281 tons. For the decade ending 1943, it averaged 238 tons yearly, but for the quinquennium ending 1948 this had risen to 592 tons. During 1949 and 1950, 3,614 tons were removed.

The Pondicherry occurrences give a clue to the manner of their formation, for here Warth noticed in a sandy shale, 7 feet thick and full of the casts of fossil shells, 'a wholesale conversion of shells into phosphate, or rather the production of interior casts of shells consisting of rich black phosphate'. Lighter-coloured, irregular phosphatic concretions and nodules are found in the same bed. The phosphoric acid brought into the sea by rivers is in part absorbed into the shelly structure of some marine organisms, and in part acts on the shells of dead organisms, converting their original calcium carbonate into phosphate of lime. The former is the more soluble of the two compounds, so that on shoals and parts of the sea bottom exposed to currents a concentration of phosphatic material takes place. Organic matter, too, plays a considerable part in the dissolution and redeposition of phosphates around nuclei, to form nodules and concretions such as those known to be in the process of formation on the floor of the Andaman Sea today. After elevation above sea level, marine sediments containing phosphatic deposits can undergo further concentration by atmospheric agencies, surplus calcium carbonate being removed and the less soluble phosphates left behind in a more or less impure condition.

Prospectors and field geologists are advised that the rock phosphates are generically known as phosphorite and that this bears much the same relationship to apatite that limestone does to calcite, that one of its important constituents is collophanite, the hydrated calcium phosphate, $\text{Ca}_3(\text{PO}_4)_2 \cdot \text{H}_2\text{O}$, which also contains small amounts of calcium fluoride, that collophanite may be amorphous, massive, concretionary or banded, white, grey, or brown and earthy, and that it completely lacks any physical properties that are really diagnostic. It may greatly resemble limestone, or again, colloidal varieties of silica. Rock phosphates may be of commoner occurrence in India, Pakistan and Burma than has hitherto been suspected. They are easily overlooked and in other countries have often remained unnoticed for years even by experienced geologists. The bedded rock phosphates of central Yunnan, laid down under shallow water conditions in the Cambrian period, were not located by Chinese geologists until the period of the Sino-Japanese war, although they lie around Kunming, the capital city, and must have been passed over repeatedly by many earlier workers. For certain identification of any doubtful mineral phosphates in the field, chemical tests for phosphorus *must* be made.

Basic Slag produced in the basic process of steel manufacture is another important source of phosphorus for use in agriculture, the element being derived from the iron ore in which it was present originally. In Belgium, Luxembourg and Germany, owing to the high phosphorus content of the Alsatian iron ores, no less than two-thirds of their phosphoric oxide (P_2O_5) output is in the form of basic slag, etc. Slag from the Basic Bessemer process contains up to 18 per cent P_2O_5 , but slags from the open-hearth process are

considerably poorer in phosphorus, sometimes as low as 8 per cent. Still lower grades are common enough, but such slags are of no value for agricultural purposes. Large quantities of basic slag are made at Indian steel works; larger quantities still will be made in the future, but owing to the unusual purity of Indian iron ores the phosphorus content of these particular slags is usually too low to create a demand for them as a source of phosphorus. In certain slags, however, produced during the operation of the Duplex process of steel manufacture by the Indian Iron and Steel Co. Ltd at Burnpur, the P_2O_5 content is said to be about 8.7 per cent, compared with only 3.6 per cent in the slags of the normal open-hearth process.

Immense quantities of bones, mainly crushed or in the form of meal, have been shipped from India to other countries, quantities which up to about 1928 often approached, and sometimes exceeded, 100,000 tons annually and worth over a crore of rupees. Thereafter, however, as the knowledge of the value of bone meal as a fertilizer spread, this export trade has decreased, so that the average for the decade ending 1938 was about half this amount, roughly 48,000 tons. Since the last world war the totals have been much smaller still, as the figures in the table on p. 487 demonstrate. Dr M. S. Krishnan, writing in 1940, stated that about 4,000 tons of bones were used at that time annually within the country for the manufacture of superphosphate; by 1952, there were 14 factories so engaged, with an installed capacity of 150,000 tons annually, but shortage of materials, and particularly of sulphuric acid, limited production in 1948 to 21,000 tons, and in 1949 to 47,000 tons, made mainly from imported phosphate rock. The works of Fertilizers and Chemicals (Travancore) Ltd, at Alwaye, have a capacity of 100 to 200 tons per day, depending on the availability of the sulphuric acid made there from imported sulphur. The superphosphate production of this Company, using North African rock phosphate, was 11,000 tons in 1949 and 6,600 tons in 1950. In industrial processes, bones are digested with suitable solvents such as benzine, etc., to remove fats, after which they are again digested with water under pressure to remove their gelatinous contents. The Heavy Industries Panel, reporting in 1947, considered that, to establish the bone superphosphate industry on a sound footing in India, a large-scale factory is necessary with facilities for the recovery of glue and gelatine products at present wasted, but for which there is great demand both inside and outside the country. It also advocated the greater use of bone meal as a fertilizer, prohibition of the exports of bones and bone meal and the utilization of electric power for the manufacture of soluble phosphates, by a process already adopted in the United States of America which eliminates the use of sulphuric acid. In the meantime, imports of superphosphates, ammonium phosphate and other phosphatic fertilizers, which totalled approximately 15,000 tons in 1938, had increased to

29,000 tons in 1949 and to 53,445 tons, valued at Rs 36,37,072 in 1950. The average annual imports and exports of fertilizers of all kinds, for the twenty years 1929-49, are given in the tables on p. 487.

The world's reserves of phosphate rock are so great that, in the words of the Commonwealth Economic Committee's report, 'there can be no reasonable expectation of their being exhausted before further beds are discovered. It has been calculated that known deposits of which the magnitude has been estimated would last for some 1,300 years; in addition there are numerous large deposits "known and proved" but for which no satisfactory estimates are yet available'. At the same time, these are not reasons why the search for home supplies of phosphate rock should not be intensified in India, Pakistan and Burma, in order, if possible, to make them independent of imported supplies.

The poisonous, yellow, wax-like element phosphorus, which quickly takes fire on exposure to the air, is obtained by an electro-thermal process from mixtures of calcium phosphate, sand and coke; the non-poisonous, more stable, allotropic form known as 'red phosphorus' is made commercially by heating the yellow variety to 240° in an inert atmosphere. Phosphorus and several of its compounds have many important industrial uses, only a few of which can be referred to here. The chief use of the element itself is in match-manufacture, either as red phosphorus in the composition of the striking surface for safety matches, or as the sulphide, P_4S_3 , in the mixture forming the head of the ordinary match. From the element the tri- and penta-chlorides are made for use in certain branches of the fine chemical industry, including the manufacture of saccharine, sulpha drugs, vitamins, etc. Phosphorus is also employed in the vermin-destroying pastes and in the bombs, tracer bullets, incendiary shells and smoke screens of warfare. A powerful deoxidizing agent, it is used to remove oxygen from metallic copper, by adding phosphor copper to the molten metal. Phosphor copper itself is made by melting copper turnings and yellow phosphorus together in an inert atmosphere. The phosphor bronzes are another example of its utility, forming as they do some of the strongest combinations of the non-ferrous metals; thus bronzes with less than 0.3 per cent phosphorus and 4 to 6 per cent of tin are eminently suitable for springs and electrical contact mechanisms in situations where non-magnetic properties, resilience and freedom from rusting are essential. With phosphorus up to 2.5 per cent and tin from 10 to 13 per cent, hard, firm, casting alloys are obtained, widely employed in heavy-duty work where wear can be severe and corrosion has to be resisted, as in rolling-mill bearings, turntables, gun mountings and valves of various kinds. Phosphated coatings are extensively used to prevent the formation of rust on iron and steel surfaces, and as aids in the cold drawing of steel for wire, screw threads and other products requiring great reduction.

The bodies of English bone china-ware, characterized by its white colour and great translucency, contain from 27 to 46 per cent of tricalcium phosphate. Other phosphates form opacifying agents for glazes, and phosphate glasses have been prepared. As examples of the uses of phosphorus salts, the three sodium compounds of orthophosphoric acid, H_3PO_4 , may be mentioned, and it is only one of the six separate acids which the element forms. Normal sodium phosphate, Na_3PO_4 , is a valued detergent and degreasing agent, entering into the composition of cleansing, washing and scouring preparations; it is also used for softening boiler feed water and in photography. Disodium hydrogen phosphate, Na_2HPO_4 , is the ordinary 'sodium phosphate' of the laboratory; its uses, as enumerated by Dr Krishnan, include vinegar fermentation, cheese-making, fireproofing compounds, optical glass, ceramic enamels, medicine and photography. Sodium dihydrogen phosphate, NaH_2PO_4 , is a constituent of baking powders and self-raising flours. Many other elements and acids enter into the composition of commercially important compounds. Amongst them are sodium ammonium hydrogen phosphate, $Na(NH_4)HPO_4 \cdot 4H_2O$, well known to geologists as 'microcosmic salt', and used in bead tests for metals; on heating to redness this compound forms sodium hexametaphosphate $Na_3[Na_4(PO_3)_6]$, the well-known 'calgon', a preventive of the formation of scale in industrial boiler tubes, feed pipes and valves. For further details concerning the uses of phosphates the reader is referred to Dr Krishnan's brochure. Important though these phosphorus compounds are, their manufacture does not call for quantities of the raw minerals in any way comparable with the amounts required for the phosphatic fertilizers.

AMMONIUM SULPHATE

Of all the nitrogen-bearing fertilizers from which this vital element is supplied to plants to augment the quantities they obtain naturally, ammonium sulphate is by far the most important. A Royal Commission on Agriculture concluded that all Indian soils were generally deficient in nitrogen, a result largely of the ryot's failure to utilize green and farmyard organic manures, intensified by the heavy rainfall which removes large quantities of soluble nitrogen compounds. The world production of ammonium sulphate in 1948, excluding the Soviet Union and certain East European countries, was over $4\frac{1}{2}$ million tons and represented roughly 42 per cent of the production of all the nitrogenous fertilizers, including cyanamide and the nitrates of calcium, sodium and ammonium. Most of this was made synthetically from atmospheric nitrogen, but large amounts were also recovered as by-products in the carbonization of coal in coke ovens and gas retorts, the ammonia in the gases being removed by sulphuric acid.

Until recently this was the only process operating in India. The first by-product recovery ovens were started at the East Indian Railway Co.'s colliery on the Giridih coalfield in 1909, and at that time the annual production of ammonium sulphate amounted to about 400 tons per annum. Further installations followed as time went on while output expanded as indicated in the table on p. 486. Over the 13 years 1934 to 1946, out of a total make of 254,035 tons Bihar was responsible for 179,270 tons, or 70.5 per cent, and of this the Tata Iron and Steel Co. produced 82.5 per cent, the Bararee Coke Co. 8.5 per cent, the Burraker Coal Co. 7 per cent and the State Railways at Giridih 2 per cent. The remainder of the total came from the Indian Iron and Steel Co., in Bengal. As far as this source of ammonium sulphate is concerned, the average annual production for the five years ending 1950 was 19,002 tons, compared with a pre-war average of 15,508 tons. The carbonization of coal, however, no longer represents India's sole source of this fertilizer, for a synthetic product made at chemical works in Mysore and Travancore contributed an annual average of an additional 24,784 tons in 1948, 1949 and 1950.

In the early days, to her own great loss, Indian sulphate of ammonia went to enrich the fields and plantations of Java, Ceylon, Mauritius and Japan, but at the present time exports are negligible and imports have increased greatly, for this chemical is the principal artificial fertilizer used in India and is the only one employed to any extent in Pakistan. Before the last war, imports of ammonium sulphate averaged 52,000 tons per annum, rising steeply from 37,000 tons to 73,000 tons between 1934 and 1938. In 1946, 122,000 tons came into the country, followed by 142,000 tons in 1948. Sodium nitrate, of which 3,000 tons were imported in 1938, had risen to 34,000 tons in 1949, and other nitrogenous compounds from about 1,000 tons to 6,000 tons in the same period. It has been officially estimated that India's requirements of fertilizer nitrogen in 1948-9 were of the order of 75,000 tons, while actual figures for 1948 suggest a total consumption of 40,000 to 50,000 tons; expressed as ammonium sulphate alone these tonnages represent approximately 364,000 and 194,000 to 243,000 tons, respectively. During 1949 special arrangements were made for the importation of about 400,000 tons of ammonium sulphate for delivery during the two years 1949 and 1950, to meet the requirements of the Grow More Food campaign. The average imports of ammonium sulphate into India in the four years 1946-9 were about 75 per cent higher than before the war, and in 1948, at about three-quarters of the aggregate value of imported fertilizers of all kinds, ammonium sulphate accounted for the same proportion as it did in 1938; sodium nitrate rose to second place with 12 per cent, and the nitrogen group as a whole accounted for 90 per cent.

In 1943 the Foodgrains Policy Committee estimated that undivided India would require at least two million tons of artificial

fertilizers a year and recommended that, as a first step, action should be taken to establish production of nitrogenous fertilizers at the rate of 350,000 tons a year. The Government of India then decided to erect at Sindri, in Bihar, a factory capable of producing this amount of ammonium sulphate. Construction commenced in June 1946, on a site occupying about 8 square miles, on the north bank of the Damodar river, 14 miles downstream from Dhanbad, in Manbhum, and the works, completed at a cost of Rs 23 crores, went into production on 31 October 1951. Essential features of the works according to an account in the *Journal of Scientific and Industrial Research*, Vol. V, 1951, are a gas plant with 8 generating sets designed to produce 33 million cubic feet of water-gas per day by blowing air and steam over hot coke. This gas has the following composition: hydrogen 34.15, carbon monoxide 36.10, carbon dioxide 7.42, nitrogen 21.55, methane 0.75, hydrogen sulphide 0.03 per cent; after the removal of sulphur and tarry impurities by washing with cold, dilute soda ash solution, the carbon monoxide is reacted with steam, in the presence of a catalyst at high temperatures, to give hydrogen and carbon dioxide. The resultant gas as sent to the ammonia plant has the following composition: hydrogen 49.65, carbon monoxide 4.00, carbon dioxide 29.30, nitrogen 16.48, methane 0.57 per cent. The ammonia plant, with a rated capacity of 280 tons per day, operates a modified Haber-Bosch process. The gases are compressed in six stages, in the course of which their unwanted constituents and impurities are removed, the residual carbon monoxide by ammoniacal copper formate, the final outlet gas being a mixture of practically pure nitrogen and hydrogen in the ratio of 1 : 3. There are 4 independent circulating units in the synthesis plant, compressors, filters, condensers and cold-exchangers as well as the convertors with their charge of catalyst and water-cooled condensers. The catalyst is maintained at a temperature of 500 to 550° C. by heat-exchange, and a conversion rate of 14 per cent is expected; after separation of the ammonia so formed, the unconverted gases are recycled back into the system along with the make-up gas from the compression section. In the ammonium sulphate plant, gypsum from the quarries of Rajasthan is ground to 120-mesh and then mixed with carbonated ammonia liquor in a series of reaction vessels, heated by steam coils and agitated by mechanical stirrers. From the last of the reaction vessels the contents are pumped to rotary vacuum filters, where the calcium carbonate is removed, and the mother liquor dispatched to the evaporators where the crystalline sulphate is made.

Two companies made ammonium sulphate synthetically, on a small scale, before the inauguration of the giant plant at Sindri. Indeed the Mysore Chemicals and Fertilizers Ltd, with its works at Belagula, commenced the production of synthetic ammonia in 1940, obtaining the necessary hydrogen by an electrolytic process.

Between 1941 and 1950 (inclusive), 25,096 tons of ammonium sulphate had been made, as well as a quantity of 99.95 ammonia of refrigeration grade. This concern also manufactures sulphuric acid and superphosphate. Fertilizers and Chemicals, Travancore, Ltd has an ammonium sulphate plant at Alwaye with a capacity of 150 short tons per day, and made an average of 27,210 tons per annum in 1949 and 1950. Half of this amount was obtained by the direct interaction of ammonia with sulphuric acid and the remainder by the gypsum process, the latter mineral coming from mines at Ariyalur, in Tiruchirapalli. This concern uses the Bosch process for the manufacture of hydrogen, by passing water-gas and steam over a catalyst heated to about 450° to 500° C; the catalyst often used for this purpose being ferric oxide with a trace of chromic oxide.

The current demand for ammonium sulphate in India is in the neighbourhood of 400,000 tons annually but it is expected to increase rapidly in the next few years and it is stated that the Sindri factory has been planned in such a way that the out-turn can be doubled by the installation of additional equipment. Alternatively, the works can be expanded to manufacture nitric acid, ammonium nitrate or nitro-chalk fertilizers. The installation of a catalyst-making plant is under consideration, together with others to manufacture urea and methanol-formaldehyde. The 900 tons of calcium carbonate produced daily as a by-product will, it is anticipated, be turned into cement locally.

The construction of two new factories near Sindri was expected to commence in 1953. In the first of these the manufacture of ammonium nitrate and urea will be undertaken. The second will be devoted to the preparation of methanol (methyl alcohol), the plant for which has already been acquired.

Sulphate of ammonia is the only chemical fertilizer employed to any extent in Pakistan, though its consumption in the past has been very low. Consumption rose from less than 2,000 tons in 1947-8 to about 20,000 tons in 1949-50, and was expected to reach 30,000 tons in 1950-1. Until the high cost of the imported material in Karachi, or in Chittagong, is overcome by local manufacture, it is unlikely that consumption will be raised to the level required by the plans for the increased agricultural production of the country. The necessary raw materials for the manufacture of ammonium sulphate are available in Pakistan, and the Government, it is stated, are considering a scheme for the establishment of a factory with a capacity of 50,000 tons per annum in West Pakistan.

Quite apart from its use in the manufacture of ammonium sulphate and other fertilizers, ammonia is consumed on a large scale in many other processes, some of which are briefly indicated as follows: its oxidation into nitric acid, an indispensable material in the explosives, dye and chemical industry generally; its combination with carbon dioxide to form urea, $\text{CO}(\text{NH}_2)_2$, itself a potent

fertilizer with 46 per cent of nitrogen, and, furthermore, when combined with formaldehyde, the source of the aminoplastics used in lacquers and dopes for finishing motor vehicles, aircraft and furniture, in adhesives for plywoods and in coatings for non-creasing fabrics; its reactions with carbon dioxide and brine to form soda ash, Na_2CO_3 , by the ammonia-soda or Solvay process; its action on sodium to form sodamide, NaNH_2 , an intermediate product in the manufacture of sodium cyanide, NaCN , for the extraction of gold from its ores, for electroplating baths and for the preparation of hydrocyanic acid, HCN , used to fumigate warehouses and ships infested with rats and other vermin, and as a spray for fruit crops. Anhydrous ammonia is a refrigerating agent in machines for making ice and for maintaining low temperatures in cold stores, etc.; it is utilized in the annealing of metals and in the nitriding process by which hard surfaces are imparted to wrought iron, mild and special steels. It has many other applications, including the manufacture of some types of artificial silk, synthetic rubber and leather, high-octane fuels, industrial alcohol, degreasing and cleansing agents and various pharmaceutical compounds. Ammonium nitrate is an ingredient of many explosives used in mining, including some of the 'permitted' varieties for use in coal mines. Lead azide, PbN_6 , an ingredient of percussion-cap compositions and a detonating agent for high explosives, is manufactured from ammonia as a starting-point. Mixtures of ammonium nitrate and calcium carbonate form the group of fertilizers known as 'nitrochalk'. Solutions of ammonium chloride form the electrolytes of Leclanché cells and are constituents of soldering and tinning fluids, while zinc-ammonium chloride fluxes are utilized in galvanizing steel wire and sheet-metal articles.

**TOTAL PRODUCTION, IMPORTS, EXPORTS AND CONSUMPTION
OF AMMONIUM SULPHATE, 1919-46**
(in tons)

PERIOD		PRODUCTION	IMPORTS	EXPORTS	CONSUMPTION
1919-23	..	21,707	879	18,368	4,218
1924-8	..	76,593	24,145	25,330	77,408
1929-33	..	65,190	126,270	9,517	181,943
1934-8	..	77,542	260,486	16,791	321,237
1939-43	..	117,676	140,225	4,056	253,845
1944-46	..	58,817*	229,379†	nil	292,000‡

* Does not include production of factories in Mysore and Travancore.

† Includes some calcium cyanamide and nitrolim.

‡ Estimated.

AVERAGE ANNUAL IMPORTS AND EXPORTS OF FERTILIZERS, 1929-49 (in long tons)

IMPORTS

PERIOD	SODIUM NITRATE	AMMONIUM SULPHATE	OTHERS NITROGENOUS	POTASH SALTS	SUPER-PHOSPHATE	AMMONIUM PHOSPHATE	FISH MANURE	OTHERS	TOTAL	VALUE (Rs.)
1929-33 ..	4,926	25,354	442	5,193	1,831	370	2,229	14,133	53,778	60,56,319
1934-8 ..	2,822	52,097	763	4,244	6,386	4,878	1,706	4,756	77,657	78,34,181
1939-43 ..	2,521	28,085	908	1,339	3,635	635	2,782	1,552	41,617	53,78,190
1944-8 ..	5,057	97,783	2,487	1,518	643	5,453	3,767	6,111	122,837	2,63,96,720
1949 ..	35,769	121,297	6,428	5,016	948	18,666	1,814	11,812	199,750	5,37,04,837

EXPORTS

PERIOD	BONES	BONE MEAL	FISH MANURE	GUANO	HORN MEAL	AMMONIUM SULPHATE	OTHERS	TOTAL	VALUE (Rs.)
1929-33 ..	2,119	30,541	5,507	..	2,518	1,903	4,049	46,639	39,60,225
1934-8 ..	18,794	29,134	5,874	355	1,703	3,358	5,909	65,127	45,00,578
1939-43 ..	5,469	30,529	5,875	365	1,605	811	6,100	59,755	34,53,357
1944-8 ..	4,476	8,463	1,910	91	1,275	....	2,290	18,196	25,91,753
1949 ..	8,196	7,935	4	..	..	....	..	13,936	41,50,318

CHAPTER XIII

MINERALS USED IN INDUSTRY GENERALLY

SULPHUR

SULPHUR, the yellow solid which burns in air with a blue flame, emitting choking fumes of sulphur dioxide, is one of the most important minerals in modern civilization. Its annual consumption in the world as a whole now amounts to 5 or 6 million tons, most of which comes from deposits in the United States of America. As these are now unable to meet all the demands made upon them, supplies are distributed at present by the allocations of the Sulphur Committee of the International Materials Conference.

The element itself is an ingredient of gunpowder and of various fungicides, insecticides and fumigants; amongst many other applications is its use in the vulcanization of rubber and in the manufacture of enamels, dyes, ultramarine and special cements. Carbon disulphide, made by passing sulphur vapour over red-hot coke or charcoal, is a valued industrial solvent and an essential material in the manufacture of viscose rayon.

Sulphur dioxide is the source of sulphuric acid but large quantities are also consumed in the manufacture of paper, and particularly of newsprint, by the bisulphite process. It is used in sugar making, as a bleaching agent for straw, silk, wool and delicate fabrics generally, in refrigeration, in the preparation of many dyestuffs and chemicals, and in the liquified state as an industrial solvent.

A recent writer has recalled the observation of the German chemist Von Liebig, made over one hundred years ago, that 'it is no exaggeration to say we may fairly judge of the commercial prosperity of a country from the amount of sulphuric acid it consumes', with the remark that Von Liebig's touchstone also applies now. Indeed, sulphuric acid is an indispensable material, for there are few industrial processes in which it is not used for some purpose or other. It is essential for the manufacture of fertilizers, explosives, many coal-tar products, various drugs and fine chemicals, a variety of plastics, alums, paints and pigments, other acids, etc., etc. Large quantities are consumed in petroleum and coal-tar refining, in the fixation of ammonia, in bleaching and dyeing operations, in the manufacture of sulphates, in galvanizing, tinning and enamelling iron and steel, in refining copper and other non-

ferrous metals, in storage batteries and for a multiplicity of other purposes. More sulphuric acid is consumed in the United States of America than in any other country, and, according to data issued by its Bureau of Mines, of the 9,090,000 short tons used in 1944, 28.8 per cent went into the manufacture of fertilizers, 26.7 per cent into military explosives and chemicals, 11.3 per cent into petroleum refining, 6.8 per cent into coal-tar products, 6.2 per cent into the iron and steel industry, 3.7 per cent for other metallurgical purposes, 5.8 per cent into paints and pigments, 5.0 per cent into rayon and cellulose film, 1.2 per cent into industrial explosives, 0.8 per cent into the textile industry and 3.7 per cent into miscellaneous uses. In 1949, the gross production of 100 per cent sulphuric acid was nearly 11,450,000 short tons, compared with about 4,800,000 short tons in 1939. The principal increases in consumption in recent years have been for fertilizers, chemicals, rayon, cellulose, paints and pigments.

Sulphur was formerly produced on a small scale in India, Pakistan and Burma, from meagre deposits in the neighbourhood of hot springs, often situated in very isolated regions, or by the controlled roasting of pyrites, but later requirements were met by imports from Sicily, Japan and the United States, which in the seventies of the last century had already reached over 1,000 tons per annum.

E. W. Vredenburg, in 1891, noticed the occurrence of sulphur on Koh-i-Sultan, an extinct volcano in the Chagai district of Baluchistan, where an Afghan family had been extracting it for generations previously. The cessation of imports during World War II led to its exploration by E. R. Gee and others. The sulphur is found in three main areas, Batal, Miri and Narwar, at elevations of 5,200 to 6,000 feet above sea level on the southern half of the mountain, 20 to 25 miles from the Baluchistan-East Persia railway, in an almost rainless region in which no fresh water exists. It fills pores, cracks and fissures in the volcanic rocks near the surface and, with the sulphates of aluminium, iron and calcium, impregnates certain clays, themselves the result of the solfataric action of volcanic gases on the ash beds and agglomerates of the eruptions. The occurrences are very erratic in distribution, composition and size, the largest being in the form of irregular lenticles over 100 feet long and 20 feet thick. Reserves of 50,000 tons of rock containing over 50 per cent, and of 36,000 tons with 30 to 50 per cent of sulphur, were proved to be available by quarrying, but after the removal of 17,000 tons of ore to the railhead at Nok Kundi, operations were suspended early in 1945.

Sulphur deposits also occur at Sanni, in the Kachhi district of Baluchistan, and were at one time mined under the orders of the Amirs of Afghanistan. The workings were visited by Captain Hutton in 1846, but they were abandoned in the seventies after being partly destroyed by fire. The old adits were opened up by

G. de P. Cotter in 1918, and he estimated that 36,000 tons of ore, containing 10,000 tons of sulphur, were available. Later work in 1942 and 1943, by M. Haque and C. R. Gibson, revealed the presence of an ore bed occupying the base of a small semi-dome, interstratified with soft sandstones and gypsiferous shales of Oligocene age. This contains three separate seams, with a total thickness of 10 feet, averaging 44 per cent of sulphur. The reserves of ore have been estimated at 336,000 tons.

Sulphur which probably owes its origin to bio-chemical processes occurs here and there in the form of small yellow grains impregnating silt, to a depth of 2 feet, in an area of 25 to 30 acres, near Kona, in the coastal tract of the Krishna district, 7 miles from Masulipatam, Andhra. These sulphur-bearing silts are quite patchy and rarely more than a few feet across, and their sulphur content varies widely between about 2 and 45 per cent. Similar occurrences have long been known from the dried beds of tidal swamps, between the mouths of the Godavari, not far from the sea coast, but though of some scientific interest, such deposits are of no economic importance.

Small quantities of the element exist on the dying volcano of Barren Island, in the Bay of Bengal, but it is extremely doubtful if this or any other of the recorded occurrences of natural sulphur either in India or Pakistan is worth working.

The first step in the manufacture of sulphuric acid from sulphur is to burn it to produce the dioxide, SO_2 , which is then further oxidized either by the Lead Chamber, Tower, or Contact processes, to yield the trioxide SO_3 , a compound which combines with water to give sulphuric acid, H_2SO_4 . But sulphur dioxide can also be produced by roasting the metallic sulphides, particularly iron pyrites, the sulphide of iron, FeS_2 , which when pure contains 53.4 per cent of sulphur. Large quantities of the acid are made in this way and more are likely to be so made as the United States deposits, which produce over 90 per cent of the world's crude sulphur and account for over 85 per cent of the world's sulphur exports, become exhausted. The change has already commenced in the United Kingdom, where the inability of the United States to supply the whole of the 460,000 tons required in 1950, and the improbability of any future improvement, has led some of the larger manufacturers of the acid to turn to the use of pyrites once more.

It is unfortunate that no deposits of iron pyrites large enough to supply the developing Indian industry have been discovered as yet in India, Pakistan or Burma, though small occurrences are to be numbered by the score. The mineral exists in shales associated with the Coal Measures of Assam and the Punjab, and in the Eocene alum shales of the Salt Range, Kutch, Sind and other regions. It has been found in many of the Indian States, at numerous localities in West Pakistan and in the Shan States and the

Tenasserim Division of Burma; it is, in fact, a common and widely distributed mineral but, so far as is known at present, never in concentrations large and reliable enough to interest the sulphuric-acid maker. It is to be noted in passing that cubes of iron pyrites found on slabs of the calcareous slates of the Gumbum Series, in the Kurnool district of Andhra, are collected and sent to Bombay for use in Ayurvedic medicinal preparations.

In the valley of the Amjhor stream, 3 miles from Banjari, in the Shahabad district of Bihar, there is an almost flat seam in the black, carbonaceous, Bijagarh Shales of the Kaimur Series. It is about $2\frac{1}{2}$ feet in thickness, has a sulphur content of about 40 per cent, and up to 1951, 1,030 tons of the mineral had been taken from it. There are smaller occurrences of similar type at Kasisya Koh and Yogayaman Koh, also near the top of the same shales, 8 and 10 miles from Rhotas respectively. Careful prospecting in this region would probably reveal further examples, but until the seams are properly explored by underground methods their potentialities remain uncertain. At Amjhor, in a small area, 30,000 to 50,000 tons of pyrites, averaging 40 to 45 per cent sulphur, have been proved and 700,000 to 750,000 tons inferred.

In the Keonthal district, east of Tara Devi, to the south of Simla, several lenticular seams of iron pyrites occur in slates, scattered over an area of about one square mile. During 1941 and 1942, 914 tons of material, averaging between 35 and 45 per cent sulphur, had been won here and sent to a sulphuric acid plant in Agra. A similar occurrence is known in Patiala, near Tara Devi.

An occurrence in the vicinity of Polur, North Arcot district, Madras, was opened up by the Geological Survey of India in 1926 and the mineral found to be pyrrhotite, the magnetic sulphide of iron, $\text{Fe}_n\text{S}_{n+1}$, containing about 38 or 39 per cent of sulphur, in lenticular patches up to $4\frac{1}{2}$ feet thick, lying between basic charnockites and quartzites, presumably of Dharwar age. According to Arogyaswamy reserves are only of the order of 17,000 tons containing 14 to 28 per cent of sulphur. In 1950, however, re-examination by geophysical methods showed that the ore-bearing lenticles really form a vein which extends over a strike distance of more than two furlongs, and indicated the necessity of further underground exploration. Geophysical prospecting is also in progress in the vicinity of old workings in the Chitaldrug district of Mysore, worked long ago for copper ores, where indications have been found that the sulphide zone may extend over a distance of 2,000 feet, and recent diamond drilling has proved a reserve of $1\frac{1}{2}$ million tons of sulphide ore. The occurrence of pyrites in the auriferous quartz veins of the Wynaad has been referred to under Gold.

Iron pyrites occurs in notable quantity with the Gondwana coals of Tandur, Kothagudium and Sasti, in Hyderabad, as layers and lenses which are handpicked from the coal in the cleaning plants

of the collieries there. In the case of Tandur alone, it is estimated that 40 tons are available per month from the product of one seam.

Large quantities of sulphur and of sulphuric acid are made in some countries from the sulphur dioxide liberated in the roasting of the natural sulphides of zinc, copper and lead before these metals are extracted from them. Such smelter gases, for instance, were the source of the equivalent of 284,000 tons of sulphur in the United States in 1944, and accounted for 8 per cent of the British production of sulphuric acid in 1950. The sulphur contents of the lead ores smelted at Nam Tu, in Burma, and of the copper ores treated at Maubhandar, in Bihar, have hitherto gone to waste, while a proposal, made as long ago as 1920, to smelt Burmese zinc concentrates in India and recover the acid as a by-product, was abandoned. As a general approximation, it may be taken that one ton of sulphuric acid of the strength usually made in India could be obtained from one ton of Burmese zinc concentrates, the exact amount obtainable being dependent of course on the composition of the concentrates themselves and the density of the finished acid. As the production of these concentrates reached a maximum of over 78,500 tons per annum and as the grand total production between 1914 and 1940 approached 986,000 tons, some idea of the loss to the chemical industry of India and of the benefit to that of Belgium and other countries may be gained. According to J. A. Dunn, under existing smelting methods at the works of the Indian Copper Corporation, it is only practicable to recover sufficient sulphur dioxide to make 20 to 30 tons of 100 per cent acid per day. Other authorities have stated that even if full recovery were possible, the yield would be less than 30,000 short tons of such acid annually. It is understood that the question is under re-examination at present, and all that can be done here is to invite attention to the modern methods of concentrating sulphur dioxide in weak smelter-gas mixtures, and to stress that as an assured supply of sulphur is a necessity for India's economy no avoidable waste of her slender sulphur resources should be permitted. Whether any of the partially known sulphidic ore deposits will contribute to a solution of the difficulty remains to be seen. At the present time, like the indigenous resources of native sulphur, they can do little to yield adequate supplies, let alone build up essential reserves.

Yet another source of sulphur dioxide and sulphuric acid is the 'spent oxide', a waste product of the coal-gas industry. There is a legal obligation in some countries requiring the purification of gas used in towns for illuminating, heating and power purposes, and one method of removing objectionable sulphur compounds employs ferric hydroxide as an absorbent. This is converted into ferric sulphide, or ferrous sulphide and free sulphur, and when no longer usable, owing to the accumulation of free sulphur, is sold to the acid makers. Over 14 per cent of the British production,

the equivalent of 90,000 tons of sulphur, came from this source alone in 1949.

It has been suggested that sulphur might be recovered from the coke-oven gases of Indian iron and steel works, but this has not proved profitable in Europe, using coking coals with a considerably higher sulphur content than those of the Gondwana coals of India. Indeed, we have the authority of Dr J. Sanjana for the statement that about 75 per cent of the sulphur originally present in the coal is to be found in the coke, and that only 25 per cent of the low original contents could be recovered, even assuming the impossible attainment of 100 per cent efficiency in the process used. Considerable research has been done by N. N. Chatterjee and others on the problem of sulphur recovery from the highly sulphurous Tertiary coals of Assam and the Punjab, but large-scale industrial tests are indicated to confirm laboratory experiments, and the distance of the Assam coalfields from the metallurgical centres of Bihar is not helpful in this respect.

In the absence of large deposits of sulphur or sulphides, attention must sooner or later be directed to the utilization of the natural sulphates as a source of sulphur and sulphuric acid. Millions of tons of gypsum are available in India and Pakistan. It is true that at the moment only one firm, Imperial Chemical Industries, uses the method as far as Britain is concerned, but the sulphur situation is so critical there that the installation of new plants is proceeding to reduce the need to import sulphur from overseas. In August 1951, the formation of the United Sulphuric Acid Corporation was announced with the object of building a factory to produce about 150,000 tons of the acid per annum from indigenous anhydrite. The capital raised by this new enterprise was £4,200,000, and of this £3,000,000 represents Debenture stock held by institutional investors, and £1,200,000 which was subscribed by 11 participating companies, all of which are large consumers of sulphuric acid, engaged in the manufacture of fertilizers, artificial silk, heavy chemicals, dyestuffs, alumina, transparent paper, etc. The plant should come into operation in 3 or 4 years' time, will consume 240,000 tons of anhydrite a year and as a major, subsidiary by-product will make about 140,000 tons of cement clinker annually. There is another anhydrite plant in France, and one which used to operate in Germany is now in the Russian zone. The process is thus well established and although the capital costs of the plant are high, probably at least twice that of one of similar size using pyrites as a raw material, the shortage of sulphur has compelled the largest users of sulphuric acid to join in a cooperative effort to overcome it by the use of the abundant home supplies of natural calcium sulphate. Action on lines such as these may well be needed in the future to solve India's sulphuric acid demands, which show signs of increasing rapidly. It may be recalled here that gypsum, $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$, with 46.6 per cent sulphur trioxide, 32.5 per cent

lime and 20.9 per cent of water, is the hydrated form of anhydrite, CaSO_4 , with 58.8 per cent sulphur trioxide and 41.2 per cent of lime.

TOTAL IMPORTS AND PRODUCTION OF SULPHUR
AND SULPHURIC ACID, 1898-1946

PERIOD	IMPORTS		PRODUCTION
	Sulphur	Sulphuric Acid	Sulphuric Acid
	tons	tons	tons
1898-1903*	10,240	13,612	....
1904-8 ..	15,858	15,742	....
1909-13 ..	25,650	15,947	....
1914-18 ..	39,005	1,980	....
1919-23 ..	42,345	912	64,175†
1924-8 ..	78,962	588	142,128†
1929-33‡	86,977	2,245	154,665
1934-8 ..	125,764	902	180,949
1939-43 ..	144,204	494	158,440
1944-6 ..	70,349	11	100,918

* Total for 5 years. † Reckoned as 100 per cent acid. ‡ Fiscal years.

The oldest manufacturers are D. Waldie & Co., whose works were established at Konnagar, near Calcutta, over 90 years ago. Other firms making sulphuric acid, omitting coal, oil, gas and iron and steel companies and small concerns with outputs of under 1,000 tons per annum, include the Bengal Chemical & Pharmaceutical Works (since 1907); Cawnpore Chemical Works Ltd; D.C.M. Chemical Works, Delhi; Shambu Nath & Sons, Amritsar; Dharamsi Morarji Chemical Co., Thana, Bombay; Eastern Chemical Co. Ltd, Bombay (1913); Sonawala Co. Ltd, Bombay; Mysore Chemicals & Fertilizers Ltd (1940); Parry & Co., Madras (before 1909), and Travancore Fertilizers & Chemicals Ltd. An analysis of the total of 335,614 tons of the acid made in India over the decade 1929-38 follows, and the figures given in brackets are the corresponding ones for the period 1924-8. These show that 49 per cent (51.2) was made by iron, steel, coal, coke and a tinplate company in Bengal and Bihar, largely for the production of ammonium sulphate in by-product recovery coking; 13.7 per cent (20.8) in Burma, for use in petroleum refining; 0.6 per cent (1.5) by the cordite factory in Madras, and the remaining 36.7 per cent (26.5) by chemical works. The contributions of these works to the total output was distributed in the following proportions: Bombay 12.7 per cent (12.3); Bengal 12.2 per cent (7.2); Uttar Pradesh 6.7 per cent (3.4); Punjab 3.1 per cent (0.9) and Madras 2 per cent (2.7).

By 1945, there were about 42 plants making sulphuric acid in India, Pakistan and Burma, only 9 of which were using the contact

process, the remainder being chamber plants, many of which were both old and inefficient. Their combined capacity at that time was about 70,000 tons per annum and the production in that year was some 59,000 tons. Production capacity had increased to 77,000 tons in 1946, and the five-year target fixed then by the Heavy Chemicals Panel was 152,600 tons per annum. In 1945, some 73 per cent of the total production was consumed in the manufacture of fertilizers and chemicals in roughly equal proportions, and it was anticipated that the quantity taken by the fertilizer makers was likely to increase greatly.

Indian imports of sulphur have come mainly from the United States, Sicily and Japan. The world's production of native sulphur has steadily increased, from about $2\frac{1}{2}$ million tons in 1939 to an estimated rough total of 5 million tons in 1949, the output in the United States alone in that year being $4\frac{1}{2}$ million tons. The cap rocks of the salt domes of Texas and Louisiana are the source of most of this, the element being recovered by the Frasch process, under which superheated water above the melting point of sulphur is forced to depths of 600 to 1,000 feet, and the molten sulphur raised to the surface by means of compressed air.

The Sicilian sulphur deposits occur in a large region, stretching across the centre of the island, from Catania on the eastern coast as far as Agrigento in the south-west, and they are associated with limestone, sandstone, gypsum and clays of Tertiary age. The sulphur-bearing horizons contain from about 8 to about 25 per cent of the element and, although in places they almost reach the surface, it is often necessary to descend to depths approaching 1,000 feet before the rock can be won by normal underground methods, and as a consequence Sicilian sulphur is not competitive with the cheaply won American supplies in normal times. In 1950, the output was about 225,000 metric tons, compared with 377,000 metric tons in 1938.

In Japan, sulphur is found around numerous volcanic peaks extending from Hokkaido to Formosa, not only as deposits of solfataric origin in tuffs, which recall the occurrence of Koh-i-Sultan, in Pakistan, but also in the muds and clays of former crater lakes.

The world's largest deposits of iron pyrites occur in the province of Huelva in south-west Spain, extending into Seville on the east and into Portugal on the west. One of the orebodies at Rio Tinto is said to be over half a mile long, over 800 feet wide in places and persistent in depth to at least 1,500 feet below the surface. The ore it contains is massive, averaging about 48 per cent sulphur, with small quantities of copper, lead and zinc. Large tonnages of pyrites are also mined in Japan, the United States, Sweden, Norway, Canada and other countries. The world's production in 1948 exceeded $7\frac{1}{2}$ million tons, of which 1,360,000 tons came from Spain.

Though the use of sulphuric acid has been eliminated from some chemical processes in which it was once essential, new

developments of chemical technology have also created fresh demands for it in other directions, and the increasing consumption figures for the world at large do not support the view, advanced by some writers in India, that the acid is any less indispensable today than it has been in the past. As the home demand for chemicals of all descriptions increases, as it must if industry is to grow, the problem of India's sulphur supplies will become more urgent, if she is to be freed from the danger, uncertainty and expense of reliance on sea-borne, foreign imports.

Unless large pyritic deposits are unearthed as the detailed geological survey progresses, or unless the occurrences of the sulphides of copper, zinc and lead known to exist in Rajasthan, the Himalayas and elsewhere, prove on further systematic investigation to be considerably larger than the limited explorations of today indicate, it is to the recovery of sulphur from the natural sulphates that the attention of the research bureaux, capitalists and Governments alike must be directed.

SULPHATES OF IRON AND COPPER

Melanterite, or copperas, the pale green, hydrated sulphate of iron, $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$, is a common decomposition product of iron pyrites and often occurs as an efflorescence on pyritous or alum shales, from which it was at one time collected for sale. It was also obtained as a by-product from the mother liquors of the Indian alum works, but supplies from such sources have for all practical purposes ceased long ago. The mineral has not appeared in the annual returns since the period 1925-8, when small quantities varying from 3 to 15 cwt. annually were a product of the Khardang mine, in the Ladakh district of Kashmir. The India of the past used this crude iron salt in combination with certain vegetable juices to produce dyes of dark shades required by weavers and tanners. Today it is employed as a mordant and in the manufacture of ink and paint. Large quantities are available now as a by-product from the waste acid solutions which have been used to pickle black steel sheets before they are galvanized. The present output is about 2,000 tons per annum: much of this ferrous sulphate is sold as such; the rest is converted by roasting into various shades of red oxide of iron for the paint and colour trades.

Copper sulphate, chalcantite, or blue vitriol, $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$, is sometimes found as a decomposition product of copper ores. For many years it was manufactured, together with alum and copperas, from the weathered slate and refuse of the copper mines of Khetri and Singhana, in Jaipur, Rajasthan. Insignificant quantities of such natural copper sulphate are still probably collected from ancient copper workings in both India and Burma, such as those of Letpadaung, in the Chindwin valley of Burma. The efflorescences which grow on the walls of the old adits and shafts are

scraped off and dissolved in water, which after evaporation yields a mixture of the crude sulphates of copper, iron and aluminium. Copper sulphate finds its main use in India as a fungicide, particularly on tea, coffee and rubber estates, and during the last war was employed in the rot-proofing of gunny bags. It is made in the country, probably to the extent of some 900 tons per annum, by dissolving copper scrap in sulphuric acid. Imports have grown from a little over 1,000 tons per annum twenty years ago, to 1,800 or 1,900 tons per annum at the present time, agriculture accounting for 80 per cent of the total.

ALUM AND RELATED COMPOUNDS

At one time India's requirements of alum were met from internal sources by the treatment of alum shales. These are thinly bedded, easily fissile rocks containing varying quantities of small, sometimes microscopic, and well disseminated crystals and grains of iron pyrites. When exposed to the action of the air, the pyrites oxidizes, and the acid solutions so generated react upon the aluminous compounds present and form sulphates of aluminium. In actual practice the methods of treatment adopted varied in different parts of the country, the shale after mining being either exposed to atmospheric agencies for some months, or piled into heaps with alternate layers of brushwood and fired for lengthy periods. In the second part of the process, the burnt shale was lixiviated in vats or tanks with water, the liquors drawn off, concentrated, and then treated with saltpetre, wood ashes or more commonly with solutions of *reh*, the alkaline efflorescence scraped from the surface of the soil in dry parts of the country. The latter yielded an impure product in which soda alum predominated, while from the former a purer form of potash alum, the double sulphate of potassium and aluminium, $K_2SO_4 \cdot Al_2(SO_4)_3 \cdot 24H_2O$, was produced. There used to be extensive works carrying on these operations in the Shahabad district of Bihar, which obtained their supplies of pyritous shale from the Kaimur Sandstones of the Vindhyan System; at Mhurr, in Kutch, where the raw material was a soft breccia from the sub-Nummulitic Group; at Khetri and Singhana, in Jaipur, Rajasthan, using shales of Aravalli age from the local copper mines; at several places in Sind; and at Kalabagh and Kotki, in the Mianwali district of the Punjab. A detailed account of the manner in which alum was made at the last named place was given by N. D. Daru in 1910. The raw material was an alum shale taken from the base of the local Eocene rocks, with an extremely finely divided pyrite content, averaging 9.5 per cent sulphur. The product was mainly soda alum and it was sold in Delhi, Hissar, Sirsa and other centres of the tanning and dyeing trades.

The indigenous processes of manufacture resembled those discarded in Europe long ago in favour of more economical ones

using bauxite or bauxitic clays as a starting-point. The Indian industry slowly languished, until it was finally extinguished in 1928 by the combined competition of imported alum and that of alum and related chemicals produced in India itself by more modern methods. The imported products, as the table below demonstrates, have fallen to about 1,700 tons per annum from a maximum of approximately 6,400 tons per annum and, at the same time, Indian-made products had by 1950 attained a total which probably approached 20,000 tons annually.

ALUM AND THE ALUMINOUS SULPHATES, 1897-1946
(Average annual figures)

PERIOD	IMPORTS		PRODUCTION (Mianwali only)	
	Tons	Rs	Tons	Rs
1897-8 to 1902-3 ..	3,465	2,98,725	<i>Records incomplete</i>	
1903-4 to 1907-8 ..	3,385	3,03,965	284	30,705 (1904-8)
1908-9 to 1913-14 ..	3,812	3,52,710	302	42,180 (1909-13)
1914-15 to 1918-19 ..	5,828	9,52,485	318	59,715 (1914-19)
1919 to 1923 ..	6,429	12,66,270	180	69,966
1924 to 1928 ..	6,086	6,89,322	65	24,166
1929 to 1933 ..	4,993	4,37,563		
1934 to 1938 ..	2,139	1,64,182		
1939 to 1943 ..	1,885	3,57,313		
1944 to 1946 ..	1,750	3,07,672		

The Heavy Industries Panel estimated in 1946 that the total production of all double salts containing aluminium sulphate, together with alum cake, alumino-ferric and sulphate of aluminium, was between 16,000 and 17,000 tons per annum, against total requirements of some 20,000 to 21,000 tons; 10,000 tons of which were required for the manufacture of paper, 8,500 tons for the purification of water and 2,000 tons for miscellaneous purposes. There is a steady home demand for bauxite with less than 3 per cent ferric oxide for these purposes, the chemical works concerned being situated in Calcutta, Bombay, Ahmedabad, Amritsar, New Delhi, Rawalpindi, Kanpur, Ghaziabad and Bangalore.

The crude aluminium sulphate obtained by dissolving bauxite in sulphuric acid is termed 'alum-cake' and if much iron is present in the original ore, 'alum ferric cake' or 'aluminoferric' is obtained. The latter is a registered trade name of a well known firm of alum manufacturers whose products are available on the market with contents of 14, 16, 17 and 22 per cent Al_2O_3 . Aluminium sulphate in these forms is used on a very large scale for the purification of water for town supplies. It is easily soluble and causes coagulation of the suspended matter, the alumina content being precipitated in a bulky, flocculent form which absorbs or

entangles colloidal matter and pathogenic organisms, leaving the purified water clear and of good appearance, though a further sterilization by means of chlorine is often carried out. This coagulating property of aluminium sulphate, besides forming the basis of water purification, is also used in the treatment of sewage and wastes from industrial processes. Aluminium sulphate has many other important applications including its use in 'foam' fire extinguishers, in sizing paper, tanning leather, treating furs, waterproofing textiles and cleansing metals. It is also employed in the manufacture of dyestuffs, pigments and colours, in fire-resisting paints and in pharmacy. Special highly basic aluminium sulphates, known as 'alumina whites', are used as rubber fillers, as ingredients for printing inks and to a lesser extent in paints, varnishes and lacquers. The chief applications of the true alums and particularly of the ammonium and potassium varieties, are in the manufacture of fine paper and as mordanting agents in the dyeing trade.

Other aluminium salts of industrial importance include activated alumina, a powerful dehydrating, desiccating and purifying agent, used for drying gases on a commercial scale, in the refining of oils, resins and waxes, as a catalyst and catalyst carrier in organic reactions and as a separating medium in chromatographic analysis. Aluminium chloride is used in refining petroleum and as a catalyst in the manufacture of drugs, dyes and perfumes.

SALT

The natural chloride of sodium, common salt, rock salt or halite, NaCl , with 39.4 per cent of sodium and 60.6 per cent of chlorine, is a very widely and abundantly distributed mineral. During the course of geological time, salt carried in solution by rivers has slowly accumulated in the waters of the sea, and an average of a great many samples of oceanic waters shows that they contain about 3.5 per cent of saline material, the greater part of which, about 2.7 per cent, is sodium chloride, accompanied by smaller quantities of other soluble salts, including the sulphates of calcium, magnesium and potassium, the carbonate of calcium, the chloride of magnesium and the bromides of some of these elements. In hot countries salt can be recovered by the solar evaporation of sea water in shallow ponds, and much the same process proceeds naturally in the salt lakes of Rajasthan, the Dead Sea in Palestine, the Great Salt Lake of Utah in the United States of America, and in many other suitable regions of enclosed drainage. Similar processes have been in operation in earlier geological ages, when arid climatic conditions have prevailed and lagoons and land-locked arms of the sea have been periodically desiccated by evaporation and then fed by further supplies of sea water. In some such way the great deposits of rock salt, often associated with

gypsum, anhydrite and the other products of the evaporation of sea water, have been formed. They are often of great extent and thickness, exist at various geological horizons in many countries, and furnish the main supplies of commercial salt today.

For many years the average annual production of salt in the former Indian Empire, that is the area now covered by the Republic, East and West Pakistan and Burma, averaged about $1\frac{1}{2}$ million tons per annum, a quantity which was probably insufficient for the normal physiological needs of the population, without considering the quantities required by various industries. The average annual consumption of salt, on the other hand, had risen to about 2 million tons per annum by 1920, and the required balance had to be made up by imports from abroad. This was no new development, for salt was first imported into Bengal in 1817, and by 1851-2 had risen to over 110,000 tons per annum, about half the requirements of Bengal at that time. The sources of this foreign salt, which for the twenty years ending 1933 had averaged over half a million tons per annum, were mainly Aden, Egypt and Italian East Africa, though earlier in the century the United Kingdom, Germany and Spain had a share in the trade.

All salt produced in British India was subject to taxation, the last rate imposed by the former Government of India being Rs 1-9 per maund, which remained in force from September 1931 until the abolition of the Salt Tax in April 1947. The additional duty of $4\frac{1}{2}$ annas per maund imposed on foreign salt in 1931 (reduced to $2\frac{1}{2}$ annas per maund in 1933) gave much-needed protection to the indigenous industry, with the result that imports fell to an average of between 300,000 and 400,000 tons in the pre-war period 1934-8, while in Bengal alone, imports of Indian salt rose from 35 per cent of the total in 1930-1, to 92 per cent in 1936-7.

The separation of Burma in 1937 was no loss to India as far as salt is concerned, for Burma is a large importer, but the separation of Pakistan in 1947 deprived India of the rock-salt supplies previously obtained from the deposits of the Punjab Salt Range and elsewhere. Temporary shortages, however, were quickly made good by increased production from Madras, Bombay and Saurashtra, so that for the four years ending 1950 the average annual production had attained a record of 2,103,968 tons, of which Bombay supplied 28.7 per cent, Madras 32 per cent, Rajasthan 21.2 and Saurashtra 12.5 per cent. Over the same period imports continued at an average of 262,000 tons per annum, obtained mainly from Aden and the Middle East, though they fell rapidly from 249,000 tons in 1949 to 147,000 tons in 1950. The whole of the imported tonnage reaches Calcutta, whence it is distributed to the States of West Bengal, Bihar, Orissa, Assam and parts of Uttar Pradesh. The average annual consumption of salt over the four years in question, 1947-50, was therefore approximately 2,366,000 tons: it has been estimated that industrial

users required 450,000 tons of this amount, leaving 1,916,000 tons for human consumption, or some 12 lb. per head of the population, which is just about the quantity dieticians consider every individual requires annually.

Salt is not only essential to all human and animal life, it has many industrial applications besides being one of the most widely used raw materials of the chemical industry. The world's production over the period 1934-8 was about 32 million tons per annum, to which India contributed about 4.9 per cent, compared with the United States, 23.4; the Soviet Union, 13; Germany, 9; the United Kingdom, 8.6; China, 8.8; France, 6.1 and Italy 4 per cent: a great many other countries added smaller amounts to the total.

Taking industrial uses into consideration the annual total consumption of salt per head of the population in the 1947-50 period was 14.6 lb. in the case of India, compared with 122 lb. and 117 lb. for the United Kingdom and the United States, respectively. This is a measure of the far greater employment of salt in industry in these two countries, for the great bulk of their output finds its way into chemical manufactures where it appears in an imposing array of products. Chief amongst these is soda ash (sodium carbonate), which is said to take from 30 to 40 per cent of the total output. Amongst others are sodium sulphate, caustic soda, hydrochloric acid, the elements sodium and chlorine, and the compounds derived from them in general.

Salt is indispensable as a preservative of meat, fish, dairy products and foodstuffs of all kinds. It is used for pickling and salting hides, in the manufacture of soap, and on farms as an addition to stock food. The makers of coal-tar dyes and of salt-glazed ceramic goods require large quantities. It is a valuable refrigerating agent and the chief regenerator in the softening of water by the 'zeolite' process. In countries where ice-bound city streets are the rule in winter, it is extensively employed as a thawing agent. These are but a few selected applications of a common but extremely useful mineral.

Signs are not wanting that the salt situation in India, which we have attempted to outline briefly, is undergoing radical change. The target fixed for the 1951 production was roughly 2,700,000 tons, an increase of 596,000 tons over the annual average for the four years ending 1950, and of 127,000 tons over the production for 1950 alone. The official returns for 1951 show a total of 2,641,701 tons, valued at Rs 6,04,35,552 excluding 91,837 tons made by unlicensed producers. Production in 1952 amounted to over 2,826,000 tons, while the country's internal requirements, including its increasing industrial and agricultural needs, are estimated at 2,626,000 tons, leaving a surplus of more than 200,000 tons available for export. Already, in 1949, some 5,900 tons of salt had left Madras for Japan and this was followed by 18,000 tons

from West Coast ports in 1950. Exports currently allotted early in 1952 totalled 169,000 tons, and included 17,700 tons for East Pakistan and 92,000 tons for Japan from Saurashtra. The middle of the century would thus appear to mark the change-over in India, from the importation of salt to the export of its own surplus, home-made supplies to other Eastern lands suffering from a shortage of this vital commodity.

The salt supplies of Western Pakistan are derived chiefly from the rock-salt deposits of the Punjab Salt Range and of the Kohat district, in the North-West Frontier Province, as well as from the solar evaporation of sea water and brines from the saline coastal alluvium of Sind and the Mekran. Smaller quantities come from dried lake beds in Baluchistan. In 1946, the last year before the separation of the two countries, the salt deposits which later passed to Pakistan contributed 453,000 tons to a total output of 1,938,000 tons. For 1947, the year in which division took place on 15 August, complete statistics are not available, but the average annual production for the three years 1948 to 1950, according to data kindly furnished by the Geological Survey of Pakistan, was 323,700 tons, of which 51.4 per cent was obtained from Sind and 43.1 per cent from the mines of the Salt Range.

Sea Salt

Most of the salt made in Bombay, Madras and Burma comes from sea water, the processes used in its recovery in India depending entirely on solar evaporation, though on the coasts of Lower Burma the concentrated brines are finally boiled. The reservoirs and crystallizing pans lie below the level of the high spring tides, from which they are protected by embankments. The manufacturing season lasts normally from January to June. Ninety-five per cent of Bombay's salt works lie within 30 miles of Bombay itself, the rest being scattered along 500 miles of coast from Surat in the north to the neighbourhood of Mangalore in the south. Production used to average about 108 lakhs of maunds (397,764 tons) annually, of which about one-third was consumed in Bombay, one-half sent to Hyderabad (Deccan), Malabar and Madhya Pradesh, while Bengal received the remainder. In the first four years of India's separate existence, however, there have been remarkable changes in Bombay's salt production, for the output of 370,264 tons in 1947 had been increased to no less than 772,824 tons in 1950, and over the same four years Bombay was responsible for 28.7 per cent of the Indian total.

The tidal flats of the Saurashtra and Kutch coasts supply large quantities of salt, and while the production from Kutch has grown from 64,529 tons in 1948 to 71,596 tons in 1950, the corresponding figures for Saurashtra were 263,775 tons and 447,245 tons. Saurashtra alone now accounts for 12.5 per cent of the total output. The principal works are at Mithapur in the Bombay enclave of

Saurashtra; Lavanpur, in Morvi; Bedi, in Jamnagar; Kuda in Dhrangadhra; Porbandar; Bherai Creek and Veraval, in Junagad; Jaffrabad, in Janjira; Bhavnagar; and Kandla, in Kutch. The Okha Salt Works, at Mithapur, which were founded in 1927, were taken over by Tata Chemicals Ltd in 1939, and not only manufacture fine, white, crushed and vacuum salt, but are a centre at which a number of heavy chemicals and other products are made. For these both brines and bitterns are utilized, together with local coral limestone. The daily capacity of the works is soda ash, 140 tons; sodium bicarbonate, 10 tons; caustic soda, 20 tons; chlorine, 7 tons; magnesium chloride, 20 tons; bromine, $\frac{1}{2}$ ton; potassium and other bromides, $\frac{1}{2}$ ton; magnesium sulphate (Epsom Salt), 3 tons; hydrochloric acid, 7 tons; and other products.

Salt is also made from the brine of wells on the Little Rann of Kutch, at both Kharagoda and Kuda. It is fairly pure except for average amounts of 0.9 and 0.32 per cent of magnesium chloride, respectively. Here, too, with a season lasting from November to April, the heat of the sun is relied upon after the brine has been raised from the shallow wells. These brines are richer in sodium and magnesium chlorides than sea water, but contain considerably less magnesium bromide and potassium chloride. Salt in cubical crystals, known as the *baragra* variety, is a speciality of the Kuda works which also supply salt to the Alkali Works at Dhrangadhra, some 10 miles away. These have a daily output of about 50 tons of soda ash and 5 tons of calcium chloride. About 1,800 tons of magnesium chloride are obtained from Rann of Kutch bitterns from a yield of about 60,000 tons of *baragra* salt. The manufacture of magnesium chloride is described on another page. About half of the Kharagoda production is consumed in Uttar Pradesh, the remainder in Bombay and Madhya Bharat.

Large quantities of salt are made at the Mauripur works, near Karachi, in Sind, Western Pakistan. With a mean annual rainfall of 7.64 inches, normally distributed over 9 days, a dry atmosphere which is seldom still and a mean daily maximum temperature of 84° F., conditions for rapid solar evaporation are practically ideal, and it is not surprising that operations are carried on for nearly eleven months of the year. There are several other salt works in Lower Sind and the Indus delta, some of which make by-products such as Epsom salt (magnesium sulphate), potassium chloride and magnesium chloride. In the Thar Parkar district of south-eastern Sind, some 7,000 tons of salt are also recovered annually from sub-recent deposits. Over the three years ending 1950, the annual production of salt in Sind averaged 166,600 tons. The Hamun-i-Mashkel, in the desert region of north-west Baluchistan, includes a great salt marsh, dry in the cold weather with a climate ideal for salt manufacture. Explored by a few shallow pits in part, it

contains many millions of tons of salt, but on account of its inaccessibility, 40 miles from the nearest rail-head, it is only exploited on an insignificant scale for local purposes.

The Portuguese enclaves of Daman and Goa have their separate sea-salt works, the products of the latter being marketed in the Belgaum, Dharwar and Bijapur districts of Bombay as well as in parts of Mysore and Hyderabad. Saline efflorescences and weak brines are sources of the coarse salt which has been manufactured for centuries by the *uppars* of the Raichur Doab and the Surapur taluk of the Gulbarga district of Hyderabad. Two varieties are made, the first an edible salt with about 96.5 per cent of sodium chloride, and the other an impure kind with about 38 per cent of sodium chloride and 42 per cent of sodium sulphate, which is used in tanning leather. The annual production of the former averages about 1,800 tons and of the latter about 660 tons.

In Travancore there are about 14 salt works, located mainly about Cape Comorin, which contributed 53,300 tons to the Indian total in 1950, and the Travancore-Cochin State no longer has to import appreciable quantities. The salt-producing regions of Madras and Andhra are divisible into three groups: a northern one extending from Srikakulam to the Krishna district, a central group reaching from the latter district to Chingleput, while the southernmost stretches down the east coast to the vicinity of Cape Comorin. In 1948, there were approximately 50 producing centres in the three groups, with 65 separate installations turning out salt and distributed along 900 miles of coast-line. The season varies from January or February to June or July in the north, while further south it commences later, in March or April and continues into August or September. In the extreme south, on the Tirunelveli coast, salt can be harvested up to October, or even into November, depending on climatic conditions, for here, as elsewhere, evaporation depends entirely on solar heat. Output naturally varies with the vagaries of the monsoons; thus, while 812,047 tons were obtained in 1948, only 706,408 tons were forthcoming in 1950, nevertheless, Madras has been the leading producer since 1947, and between 1947 and 1950 contributed 32 per cent to the total Indian output. About 15 per cent of the Madras production is sent to Orissa, Bengal, Madhya Pradesh, Hyderabad, Mysore and Coorg, while another 2 per cent is consumed in local fish-curing. Madras salt does not attain the quality of the Bombay-made product; a representative average analysis shows 92.72 per cent sodium chloride, 2.12 per cent magnesium chloride, 1.36 per cent magnesium sulphate, 0.98 per cent calcium salts and 2.82 per cent insoluble matter. This doubtless accounts for the fact that upwards of 60,000 tons of Bombay and Saurashtra salt reach the Madras State annually.

Orissa salt comes from the coastal tracts of the Ganjam and Balasore districts. Before the partition of Bengal in 1947 there were

seven salt works along the coasts of the Midnapore, Sundarbans and Chittagong regions, but together they only made about 400 tons per annum, a trifling fraction of the province's requirements of some 550,000 tons annually. Since the partition, the two regions of West Bengal, Midnapore and the Sunderbans, have turned out up to 2,530 tons per annum (in 1950), but this again bears little relation to the actual requirements of the State. The truth is that meteorological conditions on the Bengal coast do not favour solar methods and although it has been suggested that these might be combined with boiling the concentrated brine, the question of increased costs as well as the prevalence of rain-storms due to 'Norwesters' in the productive season, are factors for due consideration, particularly as regards a recent proposal to establish a large works at Contai, in Midnapore.

Small quantities of salt are made on a cottage-industry scale for local consumption from the waters of salt springs in the Jorhat and Sadiya districts and in the Cachar Hills of Assam and from some brine wells in Manipur State, but by far the greater portion of the requirements of these States are imported.

Fuller descriptions of the methods adopted in India for the manufacture of salt than it is possible to give here are to be found in the report of the Salt Experts' Committee, constituted by the Government of India in April 1948. This report, published in 1950, also contains many analyses of the brines concerned and of the varieties of salt made from them, as well as proposals for the lay-out of a model salt works by means of which the quality of the finished product generally might be improved. These proposals have resulted in the establishment of The Central Salt Research Institute of India, opened at Bhavnagar in Saurashtra by Prime Minister Nehru in April 1954. The Institute possesses 125 acres of land near the sea for development as an experimental salt farm which will be concerned not only with the extraction of common salt, but also with the economic recovery of the many by-products obtainable from sea water and their utilization for the manufacture of other materials of importance in the industrial development of the country.

Many of the coastal districts of Burma and particularly those of southern Tenasserim—Amherst and Tavoy—yield salt from sea water, but the process followed differs from the Indian practice, the brine being concentrated in the open air by solar evaporation until its calcium sulphate content has crystallized, when the concentrated liquor is boiled almost to dryness in shallow iron pans heated by wood fires. By this means a fine white salt is produced which is more acceptable to the local market than the cruder, more coarsely crystalline Indian product. In many districts of Upper Burma and in parts of the Shan States, salt is made on a small scale from well brines or by the lixiviation of saline earths. Before it became an independent country Burma used to produce from

one fifth to one quarter of its salt requirements, the rest being imported from overseas.

Lake Salt

Salt is also made in India from subsoil and lake brines; Sambhar, the largest of the salt lakes of Rajasthan, lies in Jaipur and covers an area of some 90 square miles at its highest level, dwindling to a small central puddle by March or April. W. A. K. Christie proved, about 1910, that the muddy bottom of the lake, down to a depth of only 12 feet, contained at least 50 million tons of salt. The salt in this part of India is brought in as fine dust from the Rann of Kutch by the prevailing air currents of the hot season, while each following monsoon supplies sufficient rain-water to carry a load of it in solution into lakes such as Sambhar and other areas of enclosed drainage. There is thus a continual natural renewal of the salt supplies in these locations. In the dry weather the strong brine brought to the surface of the desiccated lake beds by capillarity quickly forms a crust of salt over the surface, which is again dissolved by the monsoon rains. Another temporary salt lake of the same character exists at Didwana, in Jodhpur, while salt is also recovered from sub-surface brines at Panchbhadra, also in Jodhpur. The combined output of all the salt sources of Rajasthan averaged 447,300 tons per annum over the years 1947 to 1950, inclusive, forming 21.2 per cent of the total production of the Republic.

Rock Salt

Towards the end of the British administration of India, about 12 per cent of the total salt production was made up of rock salt, of which 85 per cent was drawn from the mines of the Punjab Salt Range and the remainder from Kohat in the North-West Frontier Province and Mandi State in the Punjab Himalaya. Both the former occurrences are now in West Pakistan and the latter forms parts of Himachal Pradesh, in the Republic. Abul Fazl (1551-1603) mentions the salt diggings of the Punjab Salt Range in the *Ain-i-Akbari*, and the use of the mineral for 'dishes, plates and covers and stands for lamps', as well as for its more usual purposes, though it was probably the associated gypsum which was used for these ornamental articles, much as alabaster is utilized today. Following the Moguls, the mines were worked extensively under the Sikhs and first came under British control in 1849, after the Second Sikh War. In 1947, on the partition of India, they passed into the possession of the Government of Pakistan. Local tradition states that salt mining commenced about A.D. 1200, but the rock salt occurrence in the Salt Range of the Punjab is known at least from the time of Alexander the Great, as is evident from the writings of Strabo, who referred to it saying that 'in the territory of Sopeithes there is a mountain composed of fossil salt sufficient for the whole of India'.



EXTRACTION OF SALT FROM LAKE SAMBHAR, RAJASTHAN

Exposures of the Salt Marl of the Salt Range are said to appear very frequently over a distance of 134 miles and to occupy a width of 4 to 5 miles. The area of the salt-bearing strata is thus approximately 600 square miles, in which the salt zones may reach up to 275 feet in thickness, individually. At the present time mining is carried on at Khewra, Warcha and Kalabagh. Khewra itself is about 5 miles from Pind Dadan Khan, in the Jhelum district, and the salt-bearing series as exposed underground, and reading downwards, is as follows: the North Buggy Seam, 25 to 50 feet thick: marl up to 10 feet: the Buggy Seam, 150 to 200 feet thick: marl 0 to 30 feet: the Sujawal Seam, 30 to 80 feet thick: marl 60 to 100 feet: the Upper Pharwala Seam, 70 to 80 feet thick: marl 50 feet: the Middle Pharwala Seam, 70 to 80 feet thick, followed by marl and rock salt at the bottom. Thus about 300 to 450 feet of rock salt occur as thick seams, alternating with saline marls varying from 120 to 200 feet in thickness. As taken over by the British, the Khewra mines were narrow, tortuous passages, opening into huge caverns, in which no precautions had been taken for the prevention of falls from the roof. The production then was from 28,000 to 30,000 tons annually, but this soon increased after H. Warth had laid down a scheme of systematic working. The average annual output for the five fiscal years ending 1946-7 was 187,490 tons and for the two years ending 1949-50, 136,824 tons. At the Warcha mine, which is situated in the Sargodha, formerly the Shahpur district, about 9 miles from the railway station of Gunjial, the old Sikh workings were of great size and in the usual dangerous condition. Here, 20 feet of salt are extracted from a seam of much greater thickness, the remainder being of poorer quality. The average annual output for the same five years, ending 1946-7, was 38,214 tons and for the two years ending 1949-50, 27,958 tons. The red marl in which the Kalabagh salt occurs is exposed at the base of the hill on which Kalabagh itself, a town on the right bank of the Indus, in the Mianwali district, is built, and it extends for some distance northwards, cropping out in the valley of the Lun stream. The salt beds vary from 4 to 20 feet in thickness and were at one time worked in open quarries. The existing mine is about 2 miles from the town. As a rule the salt is of the same reddish colour as that of the eastern Salt Range, but much of it occurs in large transparent cubes. The output here for the five fiscal years ending 1946-7 was 20,072 tons and for the two years ending 1949-50, 14,603 tons. The geological age of the red, gypseous clay or marl of the Salt Range and the origin of the great discontinuous beds of salt which it contains are questions which have evoked much controversy. It must suffice to state here that towards the eastern end of the Range, the Salt Marl is overlain by rocks of Cambrian age and that A. B. Wynne, in his exhaustive memoir, regarded it as the oldest formation exposed, while some later observers doubt if this is its true position in the sequence.

There can be no question, however, that the rock salt deposits are of great though variable extent, and that they may be expected to continue beyond the scarp of the Range itself beneath the plateau to the north. The Punjab rock salt is usually transparent with a slight reddish tinge and as dispatched from the mines contains between 97 and 99 per cent of sodium chloride. Prior to the days of partition, its consumption was restricted mainly to the Punjab and adjoining regions, though a portion found its way into Uttar Pradesh and western Bihar. In 1950, it was announced that under a trade agreement rock salt could be imported into India from Pakistan without licensing and payment restrictions.

Immense deposits of rock salt exist in the south of the Kohat district of the North-West Frontier Province, where they were visited by Agha Abbas in 1837. The salt beds come to the surface along the axes of a series of narrow, elliptical, anticlinal folds, so that their outcrops are never continuous for any great distance. By measuring the area over which the salt is actually exposed and assuming an average thickness of 100 feet, A. B. Wynne estimated reserves of about 18 million tons, but as the salt may reasonably be expected to be accessible over a total area of 5 square miles, the actual quantity, according to later geologists, is probably not less than 1,250 million tons. The visible thickness of salt exposed in one instance is at least 1,000 feet, at a single distinct horizon, overlaid by beds of gypsum and apparently followed in conformable sequence by Nummulitic (Eocene) limestone. The salt itself is usually greyish, as contrasted with the reddish variety of the Punjab Salt Range. It is of remarkable purity, being only slightly contaminated with thin layers of clay or marl, except in the upper portion which is often impregnated with petroleum. The mineral is quarried today at Karak, Jatta and Bahadur Khel, but production is limited to strictly local demands owing to the absence of rail communication. The average annual output of the Kohat salt quarries for the five fiscal years ending 1946-7 was 31,600 tons, and for the fiscal year 1948-9, 24,370 tons.

The rock salt deposits of Mandi, in Himachal Pradesh, were first described by Moorcroft in 1841 and their precise age still remains doubtful. They occur in a zone of limestones, shales and sandstone, believed by some to belong to the Krol Series and by others to the Subathu (Nummulitic) Group. The salt is of a dark purplish hue, quite opaque and with a large admixture of earthy impurities, though small nests of pure, crystalline salt are occasionally met with. The average annual production for the four years ending 1950 was 4,467 tons. Recent investigations by the Geological Survey of India having indicated the salt deposits large enough for further development, the Government of India brought Messrs Escher Wyss & Co. from Zurich and are considering their brine chamber mining method for these salt mines, with a view to producing 66,000 tons of refined salt annually within the next few years, to

meet the requirements of the East Punjab, Himachal Pradesh, the Patiala & East Punjab States Union and Kashmir.

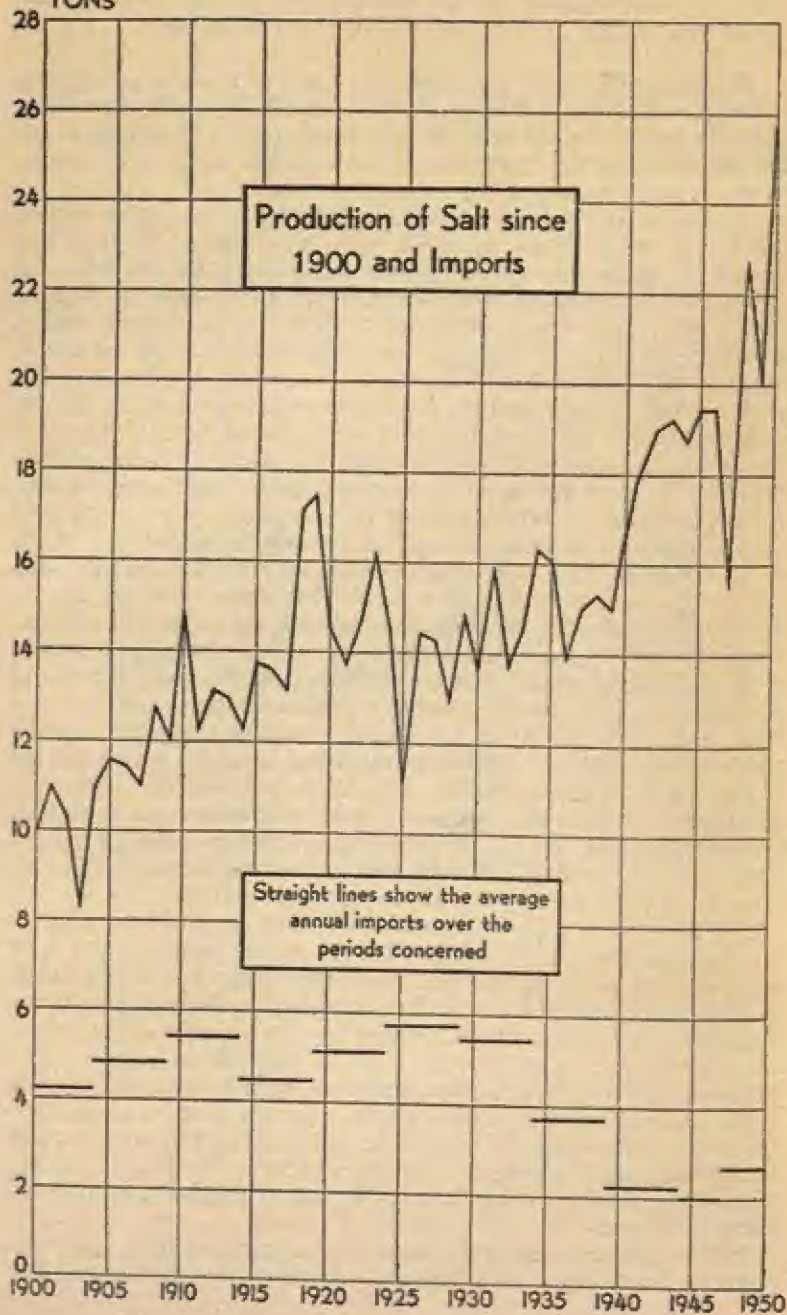
Common salt is the commercial source of its two constituent elements, sodium and chlorine, both of which are made on a large scale, the former by the electrolysis of fused salt (or of caustic soda) and the latter by the electrolysis of its aqueous solution, by which method caustic soda is also produced.

Sodium is a soft, silvery white metal, lighter than water, which can be cut with a knife or moulded in the fingers. It tarnishes rapidly in moist air and is stored under hydrocarbon oil. Its production in recent years in the United States alone is said to have reached 15,000 tons per annum. It is used in the preparation of lead tetraethyl, $\text{Pb}(\text{C}_2\text{H}_5)_4$, the 'anti-knock' agent in motor fuels; in the manufacture of sodamide, NaNH_2 , for the dyestuffs industry and an intermediate product for sodium cyanide, NaCN , itself invaluable for the extraction of gold and silver from their ores, and also employed in the nitriding of steel, in electroplating and for the preparation of hydrocyanic acid, the fumigant and vermin destructor. The synthesis of dyes, including indigo, and other organic chemicals, is stated to account for about half of the sodium metal made and consumed in the United States. The following applications furnish some further examples of its utility: as a heat-transferring medium, for instance, in the heads of aero-engine valves; in the 'modification' of alloys of the light metals, such as those of aluminium and silicon; in the manufacture of photo-electric cells, for like the other alkali metals it emits electrons when exposed to light; as a constituent of the lead-base bearing alloys (Bahn metals). Metallic thorium, titanium and uranium can be made by the interaction of sodium and their chlorides, and tantalum in the same manner from potassium fluotantalate. Sodium peroxide, Na_2O_2 , a powerful oxidizing agent used on a large scale for both laboratory and industrial purposes, is made commercially by passing dry air over heated sodium.

Chlorine is a yellowish-green, poisonous gas, about $2\frac{1}{2}$ times heavier than air. It is readily liquified and is stored in this state for transport and commercial use. Bleaching powder is made by the action of chlorine on slaked lime, and sodium hypochlorite, NaOCl , another effective bleaching agent and a powerful germicide, by its action on caustic soda or sodium carbonate. The bleach liquor required by the textile mills and paper factories in India is made, however, by the electrolysis of a solution of common salt, under conditions in which the chlorine and caustic soda so formed can react together. Sodium chlorate, NaClO_3 , a weed-killing compound, is manufactured by the electrolysis of saturated solutions of salt.

Other applications of chlorine, out of many which might be given, include the liberation of bromine from the magnesium

HUNDRED
THOUSAND
TONS



bromide of bitterns and of sea water; the preparation of carbon tetrachloride, CCl_4 , a solvent of fats, a dry-cleaning fluid for textiles and a component of some fire-extinguishers; of chloroform, CHCl_3 , the anaesthetic and of chloral, CCl_3CHO , the hypnotic drug; of sulphur chloride, S_2Cl_2 , used in rubber processing, and of various organic solvents, dyestuffs and other derivatives. Hydrochloric acid, HCl , can be made by the direct combination of hydrogen and chlorine, both of which are by-products in the electrolytic manufacture of caustic soda from solutions of common salt.

Public health authorities sterilize drinking-water supplies and disinfect the contents of public swimming baths with chlorine as well as using it in the treatment of sewage effluents. In metallurgy, chlorine is the basis of the most important of all the gold-refining

AVERAGE ANNUAL PRODUCTION AND IMPORTATION OF SALT IN INDIA, 1898-1946

PERIOD	PRODUCTION	IMPORTS	TOTAL	PROVINCIAL SHARES OF PRODUCTION				
				BOMBAY AND SIND	MADRAS	NORTH-EAST INDIA	BURMA	ROCK SALT
	Tons	Tons	Tons	%	%	%	%	%
1898-1903	979,572	433,754	1,413,326	37.6	30.4	29.7	2.2	11.2
1904-8 ..	1,167,785	484,940	1,652,725	36.9	33.3	27.4	2.2	10.3
1909-13..	1,301,901	552,299	1,854,200	37.0	31.0	29.0	2.1	11.5
1914-18..	1,395,102	443,575	1,838,677	34.9	30.3	31.2	2.8	12.7
1919-23..	1,530,272	517,894	2,048,166	35.0	31.4	30.2	3.2	11.6
1924-8 ..	1,343,587	580,943	1,924,530	34.0	33.0	31.3	1.6	12.1
1929-33..	1,452,264	548,788	2,001,052	34.8	31.0	32.4	1.8	11.8
1934-8 ..	1,548,496	368,934*	1,917,430	37.3	28.0	31.7	3.0	11.7
1939-43..	1,748,469			37.3	28.7	34.0		
1944-6 ..	1,149,232			35.1	28.5	35.0		

* Burmese imports are not included after March 1937.

AVERAGE ANNUAL PRODUCTION AND IMPORTATION OF SALT IN THE INDIAN REPUBLIC, 1947-50

PERIOD	PRODUCTION	IMPORTS	TOTAL	STATE SHARES OF PRODUCTION				
				BOMBAY	MADRAS	RAJASTHAN	SAURASHTRA	ROCK SALT
	Tons	Tons	Tons	%	%	%	%	%
1947-50..	2,103,968	261,949	2,365,917	28.7	32.0	21.2	12.3	0.2

MINERALS USED IN INDUSTRY
SOURCES OF INDIAN SALT IMPORTS, 1898-1950

PERIOD	AVERAGE ANNUAL TOTAL	SHARES OF VARIOUS COUNTRIES							IMPORTED INTO	
		UNITED KINGDOM	GERMANY	ADEN	ARABIA	EGYPT	SPAIN	ITALIAN EAST AFRICA	CALCUTTA	RANGOON
	<i>Tons</i>	%	%	%	%	%	%	%		
1898-1903 ..	433,754	56.1	13.1	11.4	9.9	6.5	..	..	89.8	10.1
1904-8 ..	484,940	45.2	14.0	14.4	12.4	5.6	7.4	..	88.8	11
1909-13 ..	552,299	29.8	10.3	16.7	11.8	10.3	16.6	4.3	90	10*
1914-18 ..	443,575	17.6	1.4	25.6	1.4	30.3	13.5	10.2	90	10*
1919-23 ..	517,894	17.1	8.5	31.1	..	21.5	10.6	11.0	88	12*
1924-8 ..	580,943	14.2	8.2	33.4	..	22.4	9.0	9.3	85	15*
1929-33 ..	548,788	6.6	11.2	46.1	..	11.6	6.8	15.1	85	15*
1934-8 ..	368,934	..	15.8	70.6	..	5.4	..	1.3	..	..
1939-43 ..	223,711	..	1.8	55.6	..	29.4	..	..	..	..
1944-6 ..	206,381	..	..	25.0	..	66.6	..	..	..	..
1947-50 ..	261,950	..	..	58.9	..	21.1	..	..	..	..

* Approximate percentage.

processes, and the bulk of the world's output of gold, including that of the Witwatersrand, in South Africa, is treated in this way. It is also used in the refining of silver, for the purification of crude bismuth and the removal of zinc from lead; in the recovery of tin from cans and other tin-plate scrap, and in the preliminary stages of the production of zirconium from zircon by the Kroll process.

OTHER SODIUM COMPOUNDS

Many tracts of barren land, known as *usar*, exist on the Indo-Gangetic plain from Bihar, through the upper portion of Uttar Pradesh to parts of the Punjab, Rajasthan and Sind, over the surfaces of which efflorescences of sodium carbonate and sulphate are common, and the concentration of alkalis in the soil in some places is great enough to lower its fertility or to throw it completely out of cultivation. In parts of Bombay, Rajasthan, Baluchistan and the Punjab, saline soils containing an excess of sodium chloride are common. Such conditions are not confined entirely to upper India and Pakistan, for barren, soda-bearing soils are widespread in the South Arcot, Tiruchirapalli, Chittoor, Guntur, Tumkur, Chitaldrug and other districts of south India. They also prevail in parts of the dry zone of upper Burma. The salty crusts which form on the surface of the alluvium are known as *reh* in Bihar and Uttar Pradesh, as *thur* in the Punjab, as *chowhi chakke* in Mysore and *sapaya* in Burma, and the crude mixtures of sodium salts made from them are termed *saji matti* in northern India.

Sodium salts are present in all ground waters but certain conditions are necessary before they reach toxic concentrations and give rise to efflorescences. These conditions include a high water-table and a low hydraulic gradient, with a correspondingly sluggish responsive movement of both ground and surface water. When these exist in a monsoon climate which permits intensive evaporation during the dry season, capillary action soon brings the stagnant solutions to the surface, where their contents crystallize as the familiar white deposits of the *usar* lands. It should be added, for a true appreciation of this serious problem, that the ground slope of many parts of the Indo-Gangetic plain is but one foot per mile, and, further, that water percolation from the great systems of irrigation canals has raised the level of the *reh*-polluted, subsoil waters in some areas and by thus promoting increased evaporation has resulted in an extension of the soda-bearing, *reh* lands.

In days previous to the importation of sodium salts from foreign countries, there was a thriving industry in the extraction of such products by simple processes of lixiviation and solar evaporation and they were used in the manufacture of crude glass and soap, for curing hides and skins and in tanning leather. Today these alkaline earths can still be purchased in the bazaars and they are hawked about the residential quarters of the town, where they are used by *dhobis* in laundering and by the poorer classes for the cleansing of cooking utensils and domestic purposes generally. In 1934, P. K. Ghosh found that crude soap was still being made from alkaline encrustations gathered near the banks of the Bokh and Khari rivers, near Parantij, Ahmedabad district, Bombay, where it was said to yield an annual income of about two lakhs of rupees to its makers.

The compositions of some *reh* soils, of *reh* itself and of the *saji matti* made from it are given below:

ANALYSES OF SODA SOILS, *REH* AND *SAJI MATTI*

	*	**	†	††	‡	‡‡
	%	%	%	%	%	%
Sodium carbonate ..	2.92	0.80	9.66	4.68	27.02	31.44
" bicarbonate ..	6.04	1.81	8.55	3.96	4.28	6.55
" sulphate ..	..	3.40	8.66	1.19	33.98	..
" chloride ..	0.34	2.43	1.92	3.88	..	..

* Alluvial soil, Kanoni, Meerut district, Uttar Pradesh.

** Alluvial soil, Loni, Meerut district, Uttar Pradesh.

† *Reh*, Moradabad district, Uttar Pradesh. Average of 4 samples.

†† *Reh*, Meerut district, Uttar Pradesh. Average of 4 samples.

‡ *Saji matti* from Kanpur.

‡‡ *Saji matti* from Dehra Dun.

As a general rule it is only seldom that *reh* as collected contains more than 10 per cent of soluble constituents; the remainder being admixed silt.

B. C. Gupta has described how in the Moradabad district the *reh* deposits form flaky patches, either in the form of crowded assemblages of small, crumbling cones, or as separate layers of white salts, from a fraction of an inch to $1\frac{1}{2}$ inches in thickness, in the soil and on its surface; both forms are very liable to fall into impalpable powder and give rise to loose, superficial dust. This dust does not exist as extensive sheets, but occurs rather in small patches and plots, scattered over the sparsely grass-covered, infertile land. Exceptionally, however, as in the Loni area of Meerut, the deposits are almost continuous, glistening white and incipiently crystalline, often upwards of three inches thick and with an average of about one inch. The underlying soils of the areas concerned in Moradabad are well compacted and appear relatively impervious; left alone the growth of *reh* upon them is impeded, but periodical scraping by removing this protecting shield exposes a fresh surface to the hot sun and dry air, whereupon capillary forces again come into action, the salt-laden water reaches the top and efflorescence recommences. *Reh* growth is of course variable with the rainfall of the monsoon and the aridity of the dry season from year to year.

It is not possible to reach any clear idea of the total production of *saji matti* in northern India. At one time upwards of 2,000 tons used to reach Calcutta annually from the regions around Banaras, Azamgarh, Jaunpur and Ghazipur. It was also recovered, and probably still is, from the neighbourhoods of Kanpur, Hathras, Mathura, Shahjahanpur and Dehra Dun. In the western districts of Uttar Pradesh, the collecting season extends from November until the break of the following monsoon in June, the scraping of the encrustations and sweeping up of the dust taking place about once a fortnight, and thus giving time for the gathering in of at least ten separate growths in six months. From the Hasanpur *tahsil* of Moradabad, a small fraction of its extensive *reh* tracts, over 3,000 tons is collected every season, providing the washermen of the towns of Moradabad, Bijnor and Rampur with their detergents and the local tobacconists with a toning agent for their merchandise.

The recorded output of 'carbonate of soda' from the Punjab in 1946 was 3,036 tons, but it is very doubtful if this really represents the total *reh* collection for that year. In the Bahawalpur State of Pakistan, mixtures of earthy sodium compounds and wood ash from a low, green shrub called *kharr*, which flourishes on mud flats where they are covered with a thin layer of sand, are used for washing clothes. Saline efflorescences fairly rich in sodium sulphate and carbonate, locally termed *soudu*, occur in shallow basins of the Yadgir and Makhtal taluks, Gulbarga district, Hyderabad, and have yielded soda for local industries from very ancient times. They are still worked to supply the needs of the glass-makers in this region. The Wundwin township of the Meiktila district of Upper Burma is one of the more important producing areas in that country.

The annual output for the whole of Burma used to vary between 3,600 and 8,500 tons per annum.

Many proposals have been suggested and experiments made to extract and utilize the sodium salts from these alkaline earths on a modern, commercial scale. Thus, from 160 tons of such earths from the Nejanti and Tadaklur areas of the Tumkur district of Mysore, A. M. Sen obtained 13 tons of crude soda, averaging 29 per cent of sodium carbonate and 8 per cent of the chloride, which was sold to the Bangalore Woollen, Cotton and Silk Mills Ltd. There have been many trials in Indian glass works but without much success. The Government of the United Provinces (Uttar Pradesh), about 1918, started a demonstration factory and marketed soda ash made from *reh* soils, but after being handed over to private enterprise the works closed down about 1922.

Various exaggerated estimates of the extent and potentialities of the *reh* soils have been made in the past, some based on no more accurate observations than those made from a railway train, but J. B. Auden and B. C. Gupta supplied a needed corrective to these by their detailed, systematic work in 1940-1. These observers concluded that the potential, annual, production of sodium salts from the *reh*-infested soils of Uttar Pradesh amounts to a total of 1,400,000 tons, made up of sodium carbonate 500,000 tons, sodium bicarbonate 600,000 tons and sodium sulphate 300,000 tons, adding, however, that only the easily accessible patches can be regarded as economically workable and offering no opinion on the costs of extraction, compared with competing supplies. The opinion of Dr D. N. Wadia is final: 'Although the quantities involved are very large,' he states, 'these natural salts are distributed over such large extents of surface soil that their concentration is not found economical.'

Crude sulphate of soda, or *khari*, is made in the north-western districts of Bihar—Muzaffarpur, Saran and Champaran—which are also saltpetre-producing areas. During the 14 years, 1908-9 to 1922-3 (no figures being available for 1918-19), the total out-turn was 207,851 tons, valued at Rs 49,34,182, of which the three districts in the order named were responsible for 62, 27 and 11 per cent respectively. In 1923-4 and 1924-5 a further total of 20,778 tons was recorded, but after that time the collection of the returns was suspended, owing to the withdrawal of certain official restrictions on the manufacture of saline substances. The chief uses of *khari* are for preserving hides and as a veterinary medicine. There are said to be extensive soda efflorescences in southern Bihar, particularly south of Nawada, in Gaya, and in the Sheikpura region of Monghyr.

The brines of the salt lakes of Rajasthan contain the carbonates and sulphate of sodium as well as the chloride, or common salt. In the case of Lake Sambhar, with its 90 square miles of area, the brine which fills the otherwise dry bed in the rainy season varies little in composition from year to year, and its residue contains

about 86 per cent of salt, 10 per cent of sodium sulphate and 4 per cent of sodium carbonate. The bitterns, or mother liquors left after the salt has been removed, contain from 62 to 66 per cent of the chloride, 21 to 23 per cent of the sulphate, 12 to 13 per cent of the carbonate and from nothing to 3 per cent of the bicarbonate of soda. These bitterns are pumped into reserved areas, and in one of them, known as the East Lake Area, J. B. Auden has estimated a reserve of 1,700,000 tons of sodium sulphate. 'It is clear', he writes, 'that the quantities of sodium sulphate and carbonate liberated as potential by-products during the production of common salt are large. An annual production of 200,000 tons of sodium chloride at Sambhar would appear to involve the release every year of approximately 23,000 tons of sodium sulphate.'

Furthermore, there are known to be some 50 million tons of crude sodium chloride available in the upper 12 feet of mud which forms the bed of the lake, and if the other sodium salts are present in the same proportion as in the lake brine after crystallization, Auden has calculated that 5,800,000 tons of sodium sulphate and 2,300,000 of the carbonate are available here.

The subsoil brines of the Didwana lake, in Jodhpur, with an area of about 4 square miles, contain sodium sulphate in much the same ratio to chloride as the bitterns of Lake Sambhar, though the quantities of carbonate and bicarbonate are smaller. J. M. Saha has estimated that for every 100 tons of salt produced, 25 tons of sodium sulphate are obtainable. According to H. B. Dunncliff, rich deposits of anhydrous, crystalline sodium sulphate, containing 90 per cent Na_2SO_4 , and known locally as *rohr*, occur here. This is the mineral species thenardite, well known in connexion with salt lakes in other parts of the world, and first recognized from Didwana by E. W. Vredenburg in 1904. The impure salt from the Pachbhadra basin of Jodhpur contains 21 per cent of the chloride and 67 per cent of the sulphate of sodium, betokening the presence of considerable quantities of the sulphate in the local, subsoil brines.

Until operations ceased in 1930, sodium carbonate had been won for centuries from the water of the shallow Lonar lake, on the southern border of the Buldana district of Berar, and from the alkaline mud which covers the hollow in which it lies, as its waters recede in the hot season. It was first described by J. E. Alexander, in 1824. G. E. Smith, writing in 1850, stated that operations had not been carried on regularly since 1836, when the output was about 460 tons annually; and in later years, like so many other indigenous industries, it was unable to compete successfully against cheaper, imported substances. Over the years 1909-13, a total of 446 tons, valued at Rs 16,719, was produced, followed by a blank period which lasted nine years. A revival occurred in 1923 with an output of 600 tons, worth Rs 23,750, but it was not sustained as the three following years only yielded a total of 155 tons. Working was in abeyance between 1927 and 1929, and an out-turn of

100 tons in 1930 is the last recorded. The lake has an area of 94 acres, as measured in March, 1910, and as the water evaporates, various crops of crystals, known under different local names, are formed on the bottom. They vary in composition, but the relative proportions of sodium carbonate and bicarbonate are similar in all of them and seem to consist of the definite compound $\text{Na}_2\text{CO}_3 \cdot \text{NaHCO}_3 \cdot 2\text{H}_2\text{O}$, also known as trona, mixed with varying amounts of sodium chloride and other impurities. W. A. K. Christie calculated that the total quantity of sodium carbonate in the brine was about 2,000 metric tons, while the upper $1\frac{1}{2}$ metres of the mud contained a further 4,500 tons. He believed that the sodium is derived from the basaltic rocks of the neighbourhood, which contain 1.74 per cent of sodium, while an unlimited supply of carbonic acid is available in the atmosphere and in percolating waters which leach out the alkalis from the parent rocks as carbonates or bicarbonates.

A few tons of soda are made annually in the Ladakh region of Kashmir, presumably from the waters of the alkaline springs known to exist thereabouts. The brine from the salt well at Bawgyo, in the northern Shan State of Hsipaw, in Burma, contains about 25.5 per cent of total salts, an analysis of which showed 60.48 per cent of sodium chloride and 36.24 per cent of sodium sulphate. It has a possible production of about 70 tons of the sulphate per annum.

The soda industry of Sind, in Pakistan, was investigated by G. de P. Cotter in 1918-19, who states that it has existed from time immemorial. On a Survey of India map published between 1860 and 1863, one of the lakes concerned is marked 'natron-producing'. The *dhands* of the Sind desert are shallow lakes occupying suitable sites which have not been covered by the surrounding sand-hills. Water percolating into them from the basal layers of the surrounding dunes carries the salts in solution, which yields a thick crust of *chaniho* after the periodical desiccation of the dry season. Analyses of *chaniho* vary a great deal, and in this respect resemble those of *reh*. A list of a large number shows sodium carbonate ranging between 33 and 47 per cent, the bicarbonate between 21 and 23 per cent, the chloride usually under 5 per cent and the sulphate from under 1 to 5 per cent. Samples from some *dhands*, however, may contain from 30 to 50 per cent of the sulphate, and in extreme cases even more. Cotter believed that the conversion of the sulphates in the waters into carbonates is a result of bacterial action, brought about before the salts reach the *dhands* themselves. This is a modification of a theory advanced by E. Sickenburger, in the case of the alkaline lakes of Egypt. Some of the bigger *dhands* contain large quantities of soda: the two largest, Pur Chanda and Khariri, probably have up to 25,000 tons each.

The *dhands* can be divided into two groups: the first, or Nara group, is located in a belt of country, 10 to 12 miles wide, bisected

by the Nara river and extending from the south of Khairpur State into the Nawabshah taluk and the Thar Parkar district of eastern Sind; the second group lies east of Kot Jubo, in eastern Khairpur and close to the border of Jaisalmer, in Rajasthan. The Thar Parkar district has not yielded *chaniho* since 1899, as the *dhands* have become dry as a result of canalization. Taking into account both groups of the Khairpur State, Cotter found 30 producing and 40 dry *dhands*, as well as 30 which in that particular year happened to contain excessive water. In addition to these there are many more from which sodium salts have never been won by the methods practised locally. In the Nawabshah taluk, the corresponding figures were 3 producing, 20 dry and 4 *dhands* with excessive water. Over the last period for which information is available, 1939 to 1943, the total number of producing *dhands* varied between 12 and 32, with an annual average of 25 *dhands*. On the other hand, a recent publication of the Geological Survey of Pakistan states that 'in Sind and Khairpur State there are hundreds of shallow lakes (*dhands*) from which soda is recovered'. The annual production of *chaniho* is quite erratic, and as the figures given in the table below show, has averaged from under 1,000 to more than 4,000 tons per annum over the period for which statistics are available. For fuller accounts of the natural sodium compounds, Dr M. R. Sahni's comprehensive paper on Alkaline Soils and Lakes of India should be consulted.

PRODUCTION OF CHANIHO IN SIND

(Average annual figures in long tons)

	KhAIRPUR	NAWABSHAH	TOTAL
1895-6 to 1899-1900 ..	2,089	*	2,089
1900-1 to 1911-12 ..	*	*	*
1912-13 to 1916-17 ..	734	252†	986
1917-18 to 1921-2 ..	3,832	287‡	4,119
1922-3 to 1926-7 ..	2,387	185	2,572
1927-8 to 1931-2 ..	682	101	783
1932-3 to 1936-7 ..	1,696	77	1,773
1937-8 to 1938-9 ..	1,005	97	1,102
1940 to 1943 ..	1,612	*	1,612
1948 to 1950 ..	778	*	778

* No figures available. † Two years ending 1916-17 only. ‡ Average of four years only.

The local demand for this crude mixture of sodium salts is not large, though it is used to some extent in cooking, for converting sugar-cane juices into molasses, in the curing of tobacco, in laundering and in soap making, but the bulk of the mineral reaches Karachi for export. The export trade in pre-war years was about equally

divided between Indian coastal ports, particularly those of Saurashtra, Bombay and Madras, and foreign countries, among which the Arabian States and Aden accounted for by far the greater proportion, leaving the remainder for Eritrea, Ceylon, Iran and others.

The importation of sodium compounds of foreign origin continues to increase and the next table indicates this growth over recent years for the three main items, sodium carbonate, bicarbonate and hydroxide (caustic soda).

AVERAGE ANNUAL IMPORTS OF SODIUM COMPOUNDS, 1924-48
(in long tons)

PERIOD		SODIUM CARBONATE	SODIUM BICARBONATE	CAUSTIC SODA
1924-8	..	47,607	5,404	7,437
1929-33	..	54,509	5,267	14,411
1934-8	..	65,015	6,431	21,831
1939-43	..	70,945	5,080	30,265
1944-8	..	86,887	6,927	45,292

Before the last war, imports of sodium carbonate (soda ash) into India were of the order of 65,000 tons per annum and they came mainly from the United Kingdom, Magadi in East Africa, the United States of America, Italy, France and Japan. By the fiscal year 1947-8 they had risen to 67,940 tons valued at Rs 1,32,74,958, and in 1948-9 to 162,594 tons and Rs 5,31,89,000. Taking the home production into account, about 107,500 tons of sodium carbonate were consumed in India in 1944, and of this 44.6 per cent was used for general detergent purposes, and 23.3 per cent in the manufacture of glass; the paper industry took 11.1 per cent, the textile mills 8.4 per cent, the ordnance factories 2.8 per cent and the remaining 9.8 per cent formed a starting point for other sodium compounds, principally the dichromate and the silicate. Soda ash, as the Tariff Board stated in 1949, 'is of such basic importance that the quantum of its consumption is often regarded as a criterion for the industrial development of a country'. In addition to the uses already mentioned, it is employed in some processes for the manufacture of caustic soda, as a basis of many soap powders, in boiler compounds for the softening of water, in the manufacture of dyes and printing inks, in the processing of rubber and leather, in assay operations as a basic flux and in ferrous metallurgy as a desulphurizing agent of pig iron. Sodium bicarbonate, of which India consumes some 7,000 tons annually, is stated by the Heavy Chemicals Panel to be used chiefly in medicinal preparations, food materials and fire extinguishers. It is also a constituent of baking powders, Seidlitz powders and some mineral waters.

Of caustic soda, the Heavy Chemical Panel of the Planning and Development Department of the Government of India wrote in 1946, 'No country can afford to depend on imports of this essential chemical', in recommending the stepping up of its manufacture as early as possible. At that time, imports were over 45,000 tons per annum, and the existing manufacturing capacity only 12,600 tons per annum, though it has since been increased. Large quantities are used in the manufacture of soap and artificial silk, in bleaching and dyeing, in the refining of oils, in the preparation of mercerized cotton, dyestuffs, explosives and vegetable ghee, in the pulp and paper industries and, of special importance to India, in the treatment of bauxite, preparatory to its use as a source of aluminium.

The commercial uses of sodium sulphate (Glauber's Salt) include the manufacture of glass and paper, the dyeing of cotton and wool, the manufacture of sodium sulphide and thiosulphate and the metallurgical treatment of the mixed ores of copper and nickel. It also has various medicinal applications. The pre-war consumption in India was between 3,000 and 4,000 tons annually, of which the home production accounted for about 2,000 tons and the remainder was imported.

Other imported sodium salts included the following, the figures in brackets representing the approximate pre-war annual tonnages: sodium sulphide (2,000-3,000 tons), used for the removal of hair from hides before tanning, as well as for other purposes; sodium sulphite (100), thiosulphate (500), hydrosulphite (1,600), cyanide (200), tetraborate (1,600).

Attempts to found an alkali industry in India have experienced many difficulties. The Magadi Soda Co. erected a plant at Budge Budge, near Calcutta, but soon went into liquidation, about 1925. The Shri Shakti Alkali Works were established by the Dhrangadhra State, in Saurashtra, in 1923, to manufacture soda ash by the ammonia-soda process from salt obtained from the local brine wells; continuing on an experimental basis for a few years, they were closed down in 1931. Operations were resumed after large-scale alterations in 1940, under the title of the Dhrangadhra Chemical Works Ltd, in a plant designed to make 18,000 tons of soda ash per annum. In the nine years 1940 to 1948, 114,451 tons had been made. Work was suspended in April 1949.

Tata Chemicals Ltd planned the establishment of a large works at Mithapur, in Baroda, in 1939, where various heavy chemicals including soda ash, caustic soda, chlorine, bleaching powder, and hydrochloric acid, were to be made from salt obtained from sea water. The soda ash plant, with a daily capacity of 50 tons, was started in 1944, worked intermittently for about three years, was redesigned and resumed continuous operation towards the end of 1947, only to close down in April 1949, after turning out 19,367 tons of soda ash. In this case as in that of the previous one, large-scale imports of the foreign product brought work to a standstill.

The works of the Alkali Chemical Corporation Ltd are at Khewra, in the Jhelum district of West Pakistan, but no details are available regarding them.

The annual demand for soda ash at present has been variously estimated at from 90,000 to 120,000 tons per annum (the latter figure including Pakistan). The rated capacity of the two Indian works mentioned is 46,000 tons per annum. In February 1950, the Government of India raised the duty on imported soda ash to 40 per cent *ad valorem* in the case of a British colony and 50 per cent if manufactured elsewhere. At the same time the two companies mentioned above were granted a subsidy of Re 1 per ton.

BORAX

Borax, or tincal, is a hydrated borate of sodium, $\text{Na}_2\text{O} \cdot 2\text{B}_2\text{O}_3 \cdot 10\text{H}_2\text{O}$, containing 36.6 per cent of boron trioxide when fresh and 69.2 per cent when its water of crystallization is removed by calcination. It arrives in India from Kashmir and western Tibet in the form of large, transparent, monoclinic prisms which soon become dull and coated with a white, earthy layer of a lower hydrate, $\text{Na}_2\text{O} \cdot 2\text{B}_2\text{O}_3 \cdot 5\text{H}_2\text{O}$, the mineral tincalconite.

The region from which the borax is derived stretches from the valley of the Puga, a tributary of the Indus, in Rupshu, eastern Kashmir, into Hundes, in south-western Tibet: between Rudok, a town of that region, and Thok Jalung (famed for its alluvial gold workings), and again, between it and the sacred Lake Manasarowar, and particularly between Roksum and the Chaka lakes, there are believed to be several large borax deposits. In the Puga valley, at an elevation of 15,000 feet, borax, associated with sulphur, is deposited by numerous hot springs and it is not improbable that the mineral occurs in other parts of Ladakh. In Hundes, both borax and common salt are obtained by lixiviating the soil from the borders of desiccated lakes in which they seem to form thick encrustations. The boron compounds here, as in other parts of the world, are connected with hot springs, solfataras and the fumaroles of exhausted and dying volcanic activity. The exhalations of boric acid from them appear to have formed sodium and calcium borates, which in normal circumstances would have been carried away in solution. Instead of this, in these slowly desiccating regions, they have been concentrated, probably over long periods of time, in the many shallow lakes which receive their intermittent saline supplies from large areas of enclosed drainage. Under the prevailing arid conditions the salts are eventually deposited on the bottoms and sides of the lakes themselves.

The earliest mention of the existence of borax in these trans-Himalayan regions by a European writer was made in 1563, and three communications regarding them were made to the Royal Society in London, in 1786, 1787 and 1789. Statistics of the imports

and sales date back to 1813, and in 1854, Marcardieu was deputed to examine the Puga deposits on behalf of a syndicate of English potters. The high-water mark of the trade was reached about 1885, when the imports into India across the frontier totalled about 1,600 tons, of which over 1,000 tons were exported, chiefly to the United Kingdom. The export trade to Europe succumbed soon after this owing to the discovery of the natural borates in the United States of America, though India continued to send the mineral to the Straits Settlements and to Hongkong. Transported over the Himalayan passes on the backs of sheep, the crude borax reached the plains of Uttar Pradesh to be refined at Ramnagar in the Naini Tal district, and elsewhere. The much smaller quantities from Ladakh reached Jagadhri, in the Ambala district, and the entrepôt of the Punjab trade.

From the beginning of the present century onwards until the registration of trans-frontier trade was discontinued in 1925, and figures for the imports of borax became no longer available, the trade was remarkably steady, averaging a little over 1,000 tons per annum, 95 per cent of which came from Tibet and the remainder from Ladakh and central Asia, the value of the mineral at the close of the period being Rs 496 per ton. Most of this was shipped through Calcutta to Singapore and Hongkong, but the export trade slowly dwindled away. In the period 1924-8 exports still averaged 105 tons per annum, in the ensuing period 1929-33 they had shrunk to 61 tons, and ten years later still further to 42 tons, valued at Rs 12,417; continuing from that time with an annual average of 30 tons, they ceased for all practical purposes in 1942, though insignificant amounts left India again in 1947 and 1949.

At the same time the annual imports of borax from overseas have increased, from an annual average of 1,076 tons in 1929-33, to 1,437 tons in 1934-8, 1,578 tons in 1938-43 and 3,292 tons, valued at Rs 15,87,827 in 1943-8. India's consumption of borax is now believed to be about 4,000 tons per annum and it is imported mainly from the United States of America and Italy.

The regrettable absence of any trade statistics after 1925 makes it impossible to evaluate the ebb and flow of trans-frontier borax imports since then. Inquiries from the Indian Trade Agent in Gartok, western Tibet, in 1951, elicited the reply that very little borax is being exported from western Tibet to India owing to the low prices ruling in the Indian market and that during the trading season June to December 1950, only a little over 3 tons was sent away. About the same time, however, the Deputy Commissioner of Naini Tal kindly informed us that 150 to 180 tons of borax was brought to Mandi Tanakpur (in the Naini Tal district) from Tibet, through Byans, Chaudans, Darma and Johar, and about 40 tons to Mandi Ramnagar; while according to the Deputy Commissioner of Almora, about 170 tons of borax were imported into Almora through Bhot Pattis during the 1950-1 season. Imports through

Garhwal and Tehri Garhwal have ceased. When the extreme isolation of the borax lakes is borne in mind, together with political conditions which render their examination and development impossible, and the almost insuperable difficulties of transportation over the highest mountains in the world, the wonder is that the trade still persists.

Borax is a mineral of very diverse industrial utility. It is consumed in large quantities in the preparation of the vitreous, enamelled coatings of iron and steel castings, such as baths, basins, stoves, refrigerators and kitchen utensils. It is a constituent of many ceramic glazes and of various types of glass. The Pyrex glasses, for instance, consist mainly of silica and boric acid with a low alkali content and no metallic oxides. They are tough, hard and heat-resistant. Such properties, and their low coefficient of expansion, lead to the employment of the borosilicate glasses for cooking utensils and laboratory ware, as well as increasingly in dairies, chemical works and food-processing factories.

Owing to its fusibility and power of dissolving many oxides, properties taken advantage of in the borax beads of determinative mineralogy, borax is a valued flux in assaying, in the refining of bullion and in the soldering, brazing and welding of metals. As a detergent it is employed in laundering, in soap manufacture, in the textile trade as a cleanser, solvent-bleach, mordant and fire-proofing agent, in paper-making for surface glazing and in leather manufacture as a neutralizing and finishing medium. Sodium perborate, $\text{NaBO}_3 \cdot 4\text{H}_2\text{O}$, a derivative of borax, has strong oxidizing properties and is used in large quantities in household washing powders, denture cleansers and toilet preparations.

The mildly antiseptic properties of both borax and boric acid are utilized to prevent rancidity in glues, pastes, starch and similar organic preparations, and to inhibit the growth of moulds on stored fruit. These properties also account for their wide application in pharmacy, cosmetics and medicine, as dusting powders, lotions and ointments; gauzes and lint; eye and mouth washes, dentifrices, deodorants, etc. Other compounds are used as dryers for oils and paints, varnishes and printing inks. It is believed by some agriculturists that traces of boron in the soil are essential for plant growth and that its presence therein prevents certain diseases in root crops.

The element boron, added to steel in the form of ferro-boron, has a hardening effect, producing the so-called 'intensified' steel. Other alloys are used as deoxidizers in the casting of certain non-ferrous metals such as the brasses and bronzes. Boron carbide B_4C is harder than carborundum and has many applications as a strong abrasive in situations where intensely hard surfaces are desirable, as in sand blast nozzles and extrusion dies. Owing to its high absorption of neutrons, it is used in the form of rods to control the operation of atomic reactors.

The great bulk of the world's supply of borax, amounting to about 94 per cent of the total production in pre-war years, comes from the United States of America, where it occurs with magnesium and potassium compounds in the brines of the Searles Lake of California, and as kernite, a hydrated sodium borate, $\text{Na}_2\text{O} \cdot 2\text{B}_2\text{O}_3 \cdot 4\text{H}_2\text{O}$, in a bedded series of Tertiary clays in the Mohave Desert of the same State. The kernite here is believed to have been formed from borax by re-crystallization induced by increased temperature and pressure, and millions of tons are available as the deposit is 4 miles long, 1 mile wide and 100 feet thick, lying from 350 to 800 feet below the surface. Deposits of the hydrated calcium borate, $2\text{CaO} \cdot 3\text{B}_2\text{O}_3 \cdot 5\text{H}_2\text{O}$, occur interstratified with Tertiary lacustrine deposits in other parts of California, and until the discovery of kernite in 1926 were an important source of supply. In 1947, the United States produced 448,150 tons of borates.

TALC, STEATITE AND PYROPHYLLITE

Steatite or soapstone is the compact, often impure, structureless variety of talc, a hydrated silicate of magnesium, $3\text{MgO} \cdot 4\text{SiO}_2 \cdot \text{H}_2\text{O}$, which possesses the distinction of being the softest of all minerals, normally has a characteristic soapy feel and is often foliated. Pyrophyllite is a hydrated silicate of aluminium, $\text{Al}_2\text{O}_3 \cdot 4\text{SiO}_2 \cdot \text{H}_2\text{O}$, which also occurs in compact masses, very slightly harder than talc and often indistinguishable from it without elaborate optical or chemical tests.

Talc schists are widely distributed amongst the crystalline rocks of India, and some kinds form the potstones which have been quarried for centuries to be carved into Hindu culinary utensils, especially in southern India. Occasionally used as a building stone for the construction of temples and palaces, it has been more often employed for the finer decorative work, or for the fashioning of images. It is extensively used in the ornamentation of temples in Orissa, in the western parts of the Bellary district of Mysore, and elsewhere. Other minor uses of similar materials include the manufacture of 'slate' pencils (especially in Burma), cups, vases, models, figurines and general bric-à-brac. 'Small idols', states V. Ball, 'are sold in large numbers at Puri and carried all over India by pilgrims as mementos of their visit to Jagannath,' and there is believed to be a trade of considerable extent in the mineral in almost every State, which does not appear in the official returns. Many of the carved ornaments of the curio shops in Indian cities, and the similar Cantonese wares of the itinerant Chinese traders, are fashioned from agalmatolite, a variety of pyrophyllite.

Steatite has many applications in industry. In the massive form it is cut into panels for switch-boards, acid-proof table tops, laboratory, laundry and kitchen sinks, tubs and tanks, as well as into linings for furnaces and stoves, for it can be sawn, turned or

machined into any desired form; it is a bad conductor of electricity and heat, is uncommonly resistant to the action of acids and corrosive melts and it hardens when heated to a high temperature. The hard-baked form of talc, misleadingly termed 'lava', has long been employed for the tips of gas burners, and the first inquiries for Indian talc from abroad, in 1886, were for material to be used for this purpose. Within the last few years pure talc of lava grade has assumed a new importance owing to its adoption for the preparation of low loss ceramic materials essential for all radio, radar, television and related instruments. Cut blocks of the solid mineral, compact enough to be intricately machined and threaded, or talc in the powdered form, free from impurities and capable of being die-pressed in a dry or semi-dry condition into the complicated shapes required by the electronic industry, were of critical, strategic importance during the last war and commanded prices far in advance of all other market varieties. Talc and the clino-enstatite bodies made from it have better di-electric properties than porcelain, as well as greater compressive and impact strength.

Talc is soft enough to mark cloth and is used for this purpose in the tailoring trade; its resistance to heat accounts for its use for marking purposes in steel works and foundries. Over 90 per cent of the world's output of talc, perhaps amounting to about half a million tons per annum, however, is marketed in the form of fine powder and is widely employed in the paint industry as an extender; in ceramics for the manufacture of porcelains, saggar bodies, enamels, tiles and refractories; as a filler for rubber, plastics, linoleum, asbestos products, textiles, polishes and soaps; as a loading agent for papers of all kinds; as a coating for roofing materials; as a dusting agent for foundry facings, glass and rubber moulds; as a lubricant in many mechanical operations; as a carrier for insecticidal dusts for both personal and agricultural employment and as a scourer for food grains such as rice and barley and for beans. The purest white kinds, ground to the consistency of flour, are the French Chalk of commerce, the basis of many cosmetic and toilet preparations in which the absorbent properties of the mineral are utilized. Talcum powders and face powders, though they account for little of the total output in quantity, doubtless represent a comparatively high proportion of its value. Some idea of the importance of these minerals may be gained from the fact that by 1944 the domestic output of ground talc, soapstone and pyrophyllite in the United States of America alone was worth more than \$5,000,000 and this figure does not include the value of cut-dimension soapstone or of imports from other countries.

Although steatite is widely distributed amongst the metamorphic rocks of India, many of the occurrences are small or consist merely of potstones derived from the alteration of basic and ultrabasic rocks, so that in the existing state of our knowledge of them only a few deposits can be classified as of really good material.

These include those of Jaipur and Mewar (Udaipur) in Rajasthan; of Mutssukota, near Tadpatri, in the Anantapur district of Andhra and of the Marble Rocks, near Jabalpur, in Madhya Pradesh; in each of these cases the mineral is believed to have been formed by the replacement of dolomite.

Three localities in Jaipur have been described by A. M. Heron: at Dagotha, a pure, milky-white to pale green talc is found as large pockets in one of the highly ferruginous portions of the Raialo Limestone; quarried on a fairly large scale, it is transported to Dausa to be milled and dispatched to various consumers both inland and overseas. In the Morra-ka-Dungar Hills, of the Hinduan district of Jaipur, a deposit which was mentioned by Hackett in 1880 extends for five miles in the form of richer pockets in a stratum associated with talcose schists, though at Gisgarh this bed is only 2 feet thick and the quality of its talc inferior to that of Dagotha. The most important deposits in Mewar are those of Ghevorla (Jeoria) which are exploited by the Udaipur Mining and Development Syndicate. They are reported to occur in a belt about 2 miles long and half a mile wide, yielding a very pure mineral, varying in colour from white to pale yellow and green. It is almost amorphous and, after sawing into blocks $3\frac{1}{2} \times 3\frac{1}{2} \times 9\frac{1}{2}$ inches, is dispatched to the United States of America and other countries; it is presumably the variety known on the American market as Indian Block Talc. The waste from the cutting operations is ground in a plant near Bhilwara, 25 miles west of Ghevorla. B. B. Gupta has reported that further deposits of variable quality used to be worked at Rikhabdeo and Khandmin, in Udaipur. Steatite has also been produced in Ajmer-Merwara, in both the Ajmer and Beawar *tahsils*; in Banswara, and from the Jakol and Dewal neighbourhoods of Dungarpur. The mineral is also found in association with white marble near Jhiri, in Alwar.

Of several localities in Madhya Pradesh, the best known is that of the Marble Rocks, where there is a group of quarries in and about the village of Bhedaghat and some 14 miles from Jabalpur. The mineral occurs in steeply dipping pockets in Dharwarian dolomites, is usually slightly schistose and snow-white to pale green or pale pink in colour. The deposits have been worked from time to time below high flood level on the northern bank of the Narmada and yield a good, fine-grained material though it is somewhat high in iron content. To the south of the Narmada there are further deposits at Gowari, Lalpur and near Rupaund, in the Jabalpur district. Near Kilekora, in the Drug district, there is another occurrence which, though now largely exhausted, still supports a flourishing cottage industry engaged in the manufacture of household potstone utensils.

The bulk of the Andhra supplies come from the Nellore district, where talc rock is found near Jogipalli, while talc schists are associated with mica schists on the right bank of the Penner river

between Kaluvaya and Thalagapur. Among the occurrences of Salem in Madras State, the bed of compact, white steatite which crosses the hill known as Isvara Malai, south-east of Isvaramurtipalaiyam, has been worked extensively at Tandakkavundanur, about 17 miles south-east of Salem, while in the Omalur taluk of the same district about 200 families are said to be engaged in carving potstone into household utensils, images, toys and similar articles, which find a ready sale in these parts of Madras. Ranking high amongst the deposits of Andhra are those of the Mutssukota forest of Anantapur, about 14 miles from Tadpatri. Here, bands of pale green talc are bedded in a siliceous dolomite and the main seam, with a thickness of about 18 inches, is mined by pillar and stall methods at a depth of 40 to 50 feet below the surface, being undercut by hand labour and extracted in blocks of as large a size as possible. Some of these are of 'lava' grade and have been exported to the United States. According to M. S. Balasundaram, high-grade talc also occurs $2\frac{1}{2}$ miles north-west of Madugupalle, in the same Tadpatri taluk. White and green varieties are also obtainable at Musalayyacheruvu, 6 miles north-west of Betamcherla, and also at Maddavaram in the Kurnool district, where the shales of the Papaghni Group are very magnesian, 'some of the layers', stated W. King, 'being nothing else but fine grey and greenish steatite'. These deposits were worked on a small scale some 35 years ago and part of the output was sold in the United States. They are now exploited by the South Indian Mining Co., who also lease the Mutssukota deposit and prepare the mineral in the powdered form for the market. In the Cuddapah district steatite is quarried at Kothagangireddipalli in the Nandimangalem taluk.

Soapstone is quarried at Metpally and Nittoor, near Pedapally, in the Karimnagar district of Hyderabad, and after being cut to the requisite sizes is used by the Sirpur Paper Mills Ltd in lining soda recovery furnaces. Material from a hill about 2 miles north-west of Kulkulapalli, in Nalgonda district, is carved into stoneware for local usage, while talcose rocks near Singareni, in Warangal district, are used for slate pencils, ink stands and the like. In the past, coarse and impure talc schists have been extensively employed in Mysore for architectural purposes and today cut blocks from Hassan are used in paper mills for furnace lining.

Soapstones and potstones abound in certain parts of Bihar, although soft chloritic schists and decomposed basic rocks are often used as potstones in addition to the true talcose rocks. In the hill ranges extending along the whole of the northern boundary of Singhbhum, from the Ranchi border to the Midnapore district of West Bengal, potstones formed by the alteration of the Dalma lavas and ultrabasic rocks are worked locally. Parallel with the copper belt, and stretching from east to west across Singhbhum into south-eastern Dhalbhum, there is a series of steatite and talc schist occurrences. The better of these lie in the hills north-west

of Bhitar Dhari, where talc is accompanied by magnesite, while one of the largest potstone deposits is situated to the west of Mahulisol, about 4 miles south-south-east of Dhalbhumgarh. Steatite and potstone resulting from the alteration of ultrabasic rocks also occur in the hills along the borders of Dhalbhum and Mayurbhanj, striking north-west from Kundarkocha towards Seraikela and more especially near Raghabdih, Kuardih and Kadal. The mineral is also to be found with the rocks of the chromite area to the west of Chaibasa and has been quarried at Nurda, 18 miles to the south of that town. Steatite deposits are worked near Isri station, west of Parasnath, in the Hazaribagh district, and supply bricks for the alkali furnaces of the Indian paper mills as well as large slabs up to 10 or 15 feet square. In the Santal Parganas, there are soapstone quarries 4 miles north of Jasidih, and others where a pale green, opalescent variety is won, about $2\frac{1}{2}$ miles south-west of Bhaludungri in Bonai, Orissa. In other parts of Orissa, there are large steatite deposits some five miles beyond Kollaru, in Koraput, where a massive variety is found as bands in quartzites and biotite gneisses. The occurrences of Antigam, Majjiguda and Minoroballi, in the same district, appear to be of poorer quality. At Mahamuhan, in Balasore, a talc-tremolite rock is abundant in a hill to the north of the village and has been worked for many years as a source of potstone. Steatite is also quarried in the Sundargarh, Keonjhar and Nilgiri districts of Orissa.

The material marketed as 'steatite' from Gorahri, in Hamirpur, and from the vicinities of Bijri and Dhankua, in the Jhansi district of Uttar Pradesh, is actually a form of pyrophyllite, but the State possesses deposits of good-quality steatite near Pithorgarh, in the Almora district. Pyrophyllite is also reported from Narwara, in the former state of Gwalior, Madhya Bharat.

In Bombay, potstone is known in both the Dharwar and Ratnagiri districts, while a large deposit of very fair quality was located by C. S. Middlemiss between Kundal and Dev Mori, in Idar. This extends for more than a mile with a width of over 200 feet, so that to a depth of only 20 feet, some 2,000,000 tons are available of finely schistose, moderately hard and fairly pure, pale blue or pinkish grey material. Further deposits are known at Ishri and Bhanmer, also in Idar.

Steatite has been worked for many years in Bijawar, Vindhya Pradesh, and is said to occur near Soreng, in Sikkim, about 15 miles north-west of Darjeeling. Compact, translucent, pale yellowish green talc occurs at several places in the Great Limestone of the Riasi *tahsil*, in Kashmir. This mineral has no noticeable cleavage and grinds down to a pure white, impalpable powder suitable for cosmetic purposes. It has been won under State agency since about 1942, at Purana Daruhr, Kunian and Katra, localities about 23 miles from Jammu.

In Pakistan, soapstone is worked departmentally by the Government of the North-West Frontier Province, at Kangrara, 30 miles from Abbottabad, in Hazara, where the production was 775 tons in 1947 and 590 tons in 1948. In the Nowshera *tahsil* of the Peshawar district there are old pits in altered Attock Shales, near Khund, whence the local inhabitants obtained supplies for soap making and water-paint. The strike continuation of the same rocks bears further abandoned pits near Kath Miani.

Steatite is found at many places in Burma, from the Kyaukpyu district in the south to Myitkyina in the north, usually in association with the serpentines and peridotites of the Arakan-Naga region. Amongst other localities which have been worked in the past are the mines of Hpa-ang in Kyaukpyu and Senlan in Minbu district, but the only recorded production from Burma is a total of 140 tons obtained between 1904 and 1928.

Complete statistics of steatite production are unobtainable for there is known to be a trade of undetermined size and value in the mineral in many parts of India, Pakistan and Burma, so that it is not possible to form even a rough estimate of its total value, especially as regards the potstones and coarser kinds used for carving and for architectural purposes. For the better qualities, won by long established firms or by departmental agencies, the position is more favourable, particularly of later years, and the output figures given in the table on p. 530 for Rajasthan, Madhya Pradesh, Madras and the North-West Frontier Province of Pakistan, can be taken as reasonably correct, as far as such grades, including the pyrophyllite of Uttar Pradesh, are concerned. For the rest, it appears that with the exception of an occasional small parcel shipped abroad, internal consumption about equalled production until 1938. In that year 800 tons were exported and from then onwards the sea-borne, external trade has expanded.

Before the last war, the United States of America produced about 45 per cent of the world's output of approximately half a million tons annually; Manchuria occupied the second place with about 15 per cent of the total; France and Italy each added a further 10 or 11 per cent, with the remainder from Norway, India, the Soviet Union, Canada, Germany, Sweden and Spain. For additional supplies of block talc and cut and sawn varieties, the American market in those days depended mainly on Italy and Japan, and the disappearance of these enemy supplies afforded India an opportunity which was quickly seized by the producers in Rajasthan, so that shipments from Jaipur, for both home and abroad, in 1941-3, were 16,752 tons. In 1941 alone, 4,468 tons were sold to the United States, 2,228 tons to the United Kingdom, 1,276 tons to Australia and East Africa and 400 tons to Iraq, Burma, Malaya and elsewhere. In addition to this, 5,627 tons went to markets in India. Before this, the United States had imported block talc from India to the extent of 287 tons in 1938,

PRODUCTION OF STEATITE, 1904-1949
(in long tons)

PERIOD	BHAR* & ORISSA	MADHYA BHARAT	MADHYA PRADESH	MADRAS (ANDHRA)	MYSORE	RAJA- STHAN	UTTAR PRADESH	OTHERS	TOTAL tons	VALUE Rs.
1904-8 ..	..	..	764	..	2,605**	..	..	54†	3,423	45,600††
1909-13 ..	1,056†	..	2,280	947	..	..	625	51†	5,059	1,89,285††
1914-18 ..	352†	73	7,037	2,033	9	120	671	..	10,795	3,34,620
1919-23 ..	90†	..	5,916	3,248	614	19,441	358	8†	30,486	4,51,009
1924-8 ..	3,956	995	6,594	3,358	988	16,022	535	27†	31,865	6,57,435
1929-33 ..	2,467	396	5,494	1,186	487	23,605	9,194	..	42,769	9,16,531
1934-8 ..	5,554	364	10,895	8,975	461	36,438	1,260	..	93,947	8,42,686
1939-43 ..	8,036	3,037	13,101	20,441	458	80,617	588	29‡	126,307	25,64,543
1944-8 ..	7,205	783	13,886	2,424	733	76,576	69	5,775§	107,451	39,18,190
1949 ..	1,638	..	2,281	555	134	16,439	61	2,096¶	23,304	10,94,343
GRAND TOTALS ..	31,065	5,648	68,948	43,167	5,889	269,258	13,291	8,040	445,306¶¶	1,10,34,292

* Includes the Eastern States Agencies from 1934-

** Statistics discontinued as untrustworthy in 1907.

† From Burma.

†† Small value from Hyderabad included.

‡ Full quantity unstated but reckoned in value.

‡‡ From Kashmir.

¶ In the decade ending 1949 a total of 31,000 tons of talc was exported abroad.

§ Includes 4,188 tons from the North-West Frontier Province, Pakistan, 1,393 tons from Kashmir, 148 tons from Ajmer-Merwara and 46 tons from Hyderabad.

¶ Includes 2,013 tons from the North-West Frontier Province of Pakistan and 83 tons from Kashmir.

892 tons in 1939 and 3,103 tons in 1940. In 1947 an American authority stated that India and Sardinia (Italy) are the chief sources of steatitic talc in sawn shapes, and there can be no doubt that the 'lava' grade mineral both from Rajasthan and to a lesser extent from Andhra has proved eminently satisfactory for the specialized purposes for which it is required. Shipments of such talc, together with large quantities of other lump and ground grades, continue to be made, especially from Jaipur and Mewar. The principal producers are the Jaipur Mining and Development Syndicate. In India powdered talc is used in soap works, paper and textile mills, rubber factories and foundries as well as for cable insulation and as a cleansing agent. Rice millers claim that polishing the grain with talc not only improves colour without loss of vitamin content, but also renders it more resistant to attack by weevils.

As the analyses in the following table indicate, the best grades of Indian talc compare favourably with those of other countries. The failure of Indian talcs in general to obtain a permanent footing in the foreign markets in the past was largely due to two causes: the substitution of greenish or other coloured material when pure white stone had been called for, and the inefficiency of the milling operations. Given rigorous attention to required specifications and the adoption of modern milling plant, there is no reason why Indian producers should not obtain and keep a much greater share of the world's trade in this essential mineral.

ANALYSES OF TALC

	*	**	†	††	‡	‡‡
SiO ₂	60.26	61.85	60.60	61.80	60.18	61.42
Al ₂ O ₃ + Fe ₂ O ₃ ..	0.31	2.61	0.30	0.80	0.24	1.67
FeO	0.12	..	0.60	0.70	0.77	..
MgO	33.04	34.52	35.30	31.40	33.45	31.50
CaO	0.28	tr.	0.40	..	tr.	tr.
Na ₂ O	0.24	..	2.80	tr.	..	0.71
K ₂ O .. ..	..	0.17	..	tr.	..	..
H ₂ O	5.01	0.60	..	5.30	5.36	4.60

* Fibrous talc from New York, U.S.A. Used as paper filler.

** Luzenach, France.

† Pinerolo, Italy. Used as a toilet material.

†† Dagotha, Jaipur. Extensively exported for cosmetic purposes.

‡ Ghevoria, Mewar. Exported in block.

‡‡ Madugupalle, Anantapur, Andhra. 'Lava' grade.

KAOLIN

Included in the kaolin group of minerals with kaolinite itself are several closely related hydrous silicates of aluminium, such as dickite and nacrite which possess the same chemical composition,

$\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2 \cdot 2\text{H}_2\text{O}$, but differ in optical properties and in their X-ray diffraction patterns. Nearly akin to them are halloysite, allophane, beidellite, anauxite and others, in which the proportion of water varies and the ratio of the silica to the alumina changes. Halloysite is a well known Indian mineral as the lithomarges of the laterites are usually mixtures of it with kaolinite. This list by no means includes all the clay-forming minerals, but only such as concern us here, and it is probably true to say that kaolinite itself is much the preponderating species in the materials described. The older theory that 'kaolin' deposits are formed entirely by surface weathering of feldspars is insufficient to account for all the Indian deposits of actual or potential commercial importance. The kaolinization of the granites and gneisses of Travancore and Malabar, for instance, has taken place under thick covers of laterite and Tertiary rocks which must have afforded them secure protection from subaerial agencies. Or, again, about the mineralized (tin and tungsten) areas of Tenasserim in Lower Burma, the kaolinization of the local granites is often profound to far greater depths than surface effects seem possible. These are matters of practical economic importance in addition to their purely scientific interest.

Besides its uses in the ceramic industry which have already been described, together with its more important occurrences, kaolin, or china clay, has many applications, principally, in India, as a dressing or stiffening agent of cotton fabrics and as a filler of paper. It has been stated that the average daily newspaper contains about one-tenth of its weight of china clay, and in most kinds of paper pulp it is used to augment the body of the finished article and produce its smooth, finished surface. Large amounts are consumed also in the manufacture of linoleum and oil cloth; smaller quantities in soaps, plastics, polishes, cosmetics and pharmacy. It figures in the hakim's pharmacopœia as an efficacious specific in the treatment of cholera and is used by the physician in Europe and America as an absorbent of toxins in the alimentary canal.

In the five years ending 1928, imports of china clay into India, consisting almost entirely of Cornish material from the United Kingdom for the textile mills of Bombay, averaged 23,216 tons per annum, valued at Rs 17,95,213. Ten years later, for a similar period ending 1938, they still averaged 24,145 tons yearly, though the value had fallen to Rs 10,86,316. During the war years imports dropped to insignificant amounts while home production rose to record heights (72,861 tons in 1946). It is regrettable that the Indian industry could not maintain its advantage; by 1947 the home output fell to 66,561 tons, in 1948 to 41,243 tons, with a slight recovery in 1949 to 42,396 tons, valued at Rs 11,73,786. Meanwhile imports, which were only 315 tons in 1946, were back to 3,313 tons in 1949. The reason lies in the fact that the Indian producer will not take sufficient care in processing a product accep-

table to the Indian user. It is no fault of the deposits themselves or of the quality of the kaolin contained in them. 'The importance of washing kaolin', writes H. Crookshank, 'is not generally realized in India. Most people think that having located a kaolin deposit all that is necessary is to dig it out and sell it.' The millowners of Bombay pay a price for Cornish kaolin four times greater than that which is given for Indian clay, and they do this because they can rely on a standardized, high-grade product of unvarying purity.

The world's annual production of china clay, excluding China and the Soviet Union, is believed to be about 3 million tons, of which Cornwall and Devon yield upwards of 30 per cent. The quality of this renowned English product is not due to any inherent property in the mineral itself, but to the care exercised in its preparation for the market. In normal times the requirements of all the main Indian users, with the exception of the cotton mills, are met from Indian sources, and there is no real reason why the home production should not meet both this and the growing demands of the future, just as it has entirely supplanted imported clay formerly used in the paper-making industry. Indian china clay properly prepared could also find markets abroad.

CHAPTER XIV

MINERALS WITH SPECIAL USES

ASBESTOS

THE term 'asbestos' embraces a number of minerals which all possess the property of splitting into fibres capable of being felted or spun together. They are divided into two groups: (1) Chrysotile asbestos, a hydrated silicate of magnesium, $Mg_3Si_2O_5(OH)_4$, and a fibrous variety of serpentine, usually occurring as narrow veins in the massive rock, and (2) Amphibole asbestos, which includes the fibrous varieties of tremolite, a calcium magnesium silicate, $Ca_2Mg_5Si_8O_{22}(OH)_2$; actinolite, a calcium magnesium iron silicate $Ca_2(Mg,Fe)_5Si_8O_{22}(OH)_2$; anthophyllite, a magnesium iron silicate, $(Mg,Fe)_7Si_8O_{22}(OH)_2$, including its variety amosite, and crocidolite which is essentially a silicate of sodium and iron. Chrysotile asbestos supplies about 90 per cent of the world's asbestos, the output of which in pre-war years approached half a million tons per annum. Most, though not all, of the Indian asbestos so far discovered belongs to the tremolite and actinolite species of the second group. Their fibres, though often of considerable length, are usually too weak and brittle for spinning, though they possess good insulating and acid-resisting properties.

Tremolite asbestos has been found at several places in Seraikela, Singhbhum and Manbhum, Bihar, and Mayurbhanj in Orissa. Most of the deposits are of little economic importance, though others, such as those of Bara Bana, Patka and Chota Dana, in Seraikela, and certain others in Singhbhum and Mayurbhanj, have yielded small tonnages in times of good demand. From Bara Bana, where the mineral occurs in the shear planes of a serpentine, asbestos 'logs', frequently up to 14 feet in length and 12 inches in diameter, have been obtained, but the mineral is too brittle for spinning. Production commenced in Seraikela in 1921, and the total quantity extracted up to the end of 1929, when working ceased, was 311 tons. A revival took place in 1932, when 90 tons were obtained, and between 1934 and 1950 small quantities have been forthcoming every year, to a total amount of 1,587 tons, valued at Rs 1,57,000 approximately. Operations started in Singhbhum in 1941 and to the end of 1946, when they ceased, 790 tons, valued at Rs 62,364, had been won. Production in Mayurbhanj dates from 1940, with a break between 1943 and 1945, and

had been responsible for 150 tons, valued at Rs 8,383, over the same period.

Amphibole asbestos occurs at many localities in Mysore and principally in the Hole-Narsipur taluk of the Hassan district, where one deposit alone has an estimated reserve of 20,000 to 25,000 tons of both anthophyllite and tremolite varieties, within a depth of 100 feet from the surface. At Kabbur, long fibrous sticks are obtainable, though they have the usual defects of brittleness and lack of tenacity. The district yielded 3,467 tons at intervals between 1906 and 1929, when operations stopped. The Bangalore district supplied 176 tons in 1920 and 1921. Many Mysore occurrences appear to be alteration products of ultrabasic rocks in close proximity to granitic intrusions. Small quantities are available when required from near Chinchaballi, in Mysore district; Maradevanaballi, in Mandya and Yedegondanaballi, in Hassan district. Veins of chrysotile in serpentine are worked desultorily near Gopalpura, in Mysore district. Mysore asbestos appeared on the market again in 1938, and from that year until the end of 1950, 561 tons, of an estimated value of Rs 29,400, have been won.

Small parcels of $5\frac{1}{2}$ and 6 tons, respectively, appear in the returns from Ajmer-Merwara, for the years 1927 and 1931; this may have come from Kaolai, where A. M. Heron found workings displaying stringers of chrysotile ramifying through serpentine. Tremolite also occurs at Sendra in ferruginous Ajabgarh Limestone. Further small parcels totalling 104 tons, valued at Rs 2,632, came from Ajmer-Merwara between 1937 and 1939, 1941 and 1942, and again in 1946. Similar material of a tremolitic character forms irregular pockets of radiating needles in large masses, in Kushalgarh Limestone, near Delawas, and in Ajabgarh Limestone, near Guda, in Alwar. Other parts of Rajasthan from which asbestos has been obtained include Dungarpur, with an output of 281 tons between 1940 and 1945; Udaipur, with a recorded production of 890 tons between 1941 and 1946, and Sirohi, now in Bombay State, which supplied 14 tons in 1946. The Dungarpur localities are near Jakal and Khymaru.

A total of 84 tons of asbestos was obtained in small amounts, spread over a number of years before 1925, from Tumkhera Khurd, Bhandara district, Madhya Pradesh; and Jhabua, in Madhya Bharat, gave 78 tons in 1947 and 1948.

Amongst other Indian occurrences of amphibole asbestos the following may be mentioned; the undeveloped deposit found by C. S. Middlemiss, in association with magnesite and serpentine, between Kundol and Dev Mori, Idar, Bombay; the prospect noted by P. N. Mukerjee near Yellingutti, Bagalkhot taluk, Bijapur district, Bombay; the presence of the mineral, as noted by D. R. S. Mehta, with serpentine and crystalline dolomitic limestone, near Bhunswara, Mirzapur, Uttar Pradesh, and the small veins in

serpentine near Payapani in the Mishmi Hills of Assam, though some of these may prove to be of chrysotile.

In Pakistan, asbestos is found with the ultrabasic intrusions to the north of Hindubagh, Baluchistan. Chrysotile is known to occur in limestone intruded by epidiorite, in the Khyber Agency, and asbestiform minerals have been reported from Waziristan and Chitral.

High-grade chrysotile asbestos, suitable for weaving, is available in commercial quantities, as far as existing knowledge goes at present, only in the Cuddapah district of Andhra. Here, in the Pulivendla taluk, an asbestos-bearing horizon was traced by A. L. Coulson for $9\frac{1}{2}$ miles, between Brahmanapalle and Lopatanutula. This zone, as the later investigations of Dr M. S. Krishnan and M. S. Venkatram have shown, is from 3 to 8 feet thick and lies in serpentinous, magnesian limestone of the Vempalle Stage, at its upper plane of contact with the lowest of two or more sills of trap rock; the mineral, of excellent, silky quality, forming anastomosing, cross-fibre veins both in the serpentinous rock and in the uppermost foot or so of the trap itself. The most promising occurrences are at Brahmanapalle and Chinnakundala, though others are known. The reserves are of the order of 250,000 tons within a depth of 660 feet along the dip slope. Chrysotile also occurs in thin sporadic veinlets, near Malkapuram and east of Joharapuram, in the Kurnool district of Andhra. Between 1924 and 1930, 200 tons of chrysotile, valued at Rs 27,954, were won from the Cuddapah district: there was no production from 1931 to 1933, and only small, experimental parcels of 8 tons, worth Rs 2,887, were taken in 1934 and 1935. Output ceased again between 1935 and 1937, and from that time until the end of 1950, 504 tons of an estimated value of Rs 5,34,564 had been extracted.

The total recorded production of asbestos of all kinds in India from 1904 to 1950 is but 9,392 tons, valued at Rs.11,19,679. The highest outputs were attained in the quinquennium 1919-23, with an annual average of 602 tons, over 93 per cent of which came from the Hassan district of Mysore. Over the ensuing 15 years, that is until the end of 1938, the annual average production was only 79 tons. A rise to 464 tons per annum followed over the period 1939 to 1943, increasing to an average of 570 tons for the three years 1944 to 1946. The distribution of the 4,031 tons raised in these eight years shows some remarkable changes, Mysore having fallen from 93 per cent of the total to 9 per cent; Seraikela contributed 28.4 per cent, Mayurbhanj 3.7 and Singhbhum 19.6 per cent. Rajasthan was responsible for 31.6 per cent, over 22 per cent of which came from Udaipur, with smaller quantities from Dungarpur and Ajmer, while the chrysotile deposits of Cuddapah yielded only 7.7 per cent of the total. In the next four years, however, the share of Cuddapah in the total of 596 tons rose to 32.7 per cent; Mysore then occupied the second place with 30 per cent and was followed

by Seraikela and Jhabua with 24·2 and 13·1 per cent respectively. Production in both Singhbhum and Rajasthan ceased in 1946. The pit's-mouth value of the Cuddapah chrysotile in pre-war years ranged between Rs 300 and Rs 400 per ton, compared with about Rs 40 per ton for the amphibole varieties.

It is impossible to enumerate here all the multifarious uses to which asbestos is put, for no other mineral combines within itself such pliability and strength of fibre, with its incombustibility, infusibility, low heat-conductivity, high resistance to electricity and sound, together with its light weight and freedom from decay and corrosion by weather, chemicals or soil. It is indispensable in modern civilization and its applications continue to expand, for there is no substitute for many of its special purposes.

Chrysotile fibres are spun into yarn and woven into fabrics of many weights and thicknesses, into ropes, tapes, felts and cloths which are made into such articles as linings for brake bands and clutches, engine packings, gaskets and jointings, insulations of many kinds, fireproof clothing and safety curtains for theatres. Shorter fibres are used as binders in cement products, mainly for the building trade, flat and corrugated sheets, wall boards, roofings, shingles, piping and guttering, floorings and fireproof coverings for wood-work. They are also processed with plasters, rubber and synthetic resins. Asbestos paper is yet another product.

For lagging boilers and steam pipes and for heat insulation in general, the amphibole varieties, such as anthophyllite and actinolite may be employed, often in conjunction with substances such as magnesia. These varieties are also said to possess a higher resistance to acids than chrysotile and to be well adapted for acid filtration.

India imports large quantities of asbestos goods, many of which are manufactured from the shorter grades and less valuable fibres, and there seems no reason why they should not be made in the country, provided the machinery employed for the purpose is adopted. The average annual imports and consumption of asbestos in India, over the period 1934 to 1946, inclusive, are given in the table below:

AVERAGE ANNUAL IMPORTS AND CONSUMPTION OF RAW
ASBESTOS, 1934-46

PERIOD		IMPORTS (tons)	CONSUMPTION (tons)
1934-8	..	1851	1918
1939-43	..	6986	7450
1944-6	..	9069	9639

The consumption of raw asbestos in India was about 11,000 tons by 1950, to which her own resources only contributed 208 tons, while the imports of the mineral cost the country over Rs.95 lakhs; moreover, the figures quoted do not include imported products made from asbestos, which in 1949 alone exceeded a value of Rs 66 lakhs. Here, then, is a situation requiring a more intensive development of the home supplies.

The average annual world production of asbestos of all kinds during 1934-8 was 447,000 tons, of which Canada alone produced about 60 per cent, entirely of chrysotile. By 1948, world production had risen to 846,700 tons (excluding Russia) and three-quarters of this amount again came from Canada; the African countries of Southern Rhodesia, South Africa and Swaziland between them added a further 15½ per cent, while the remaining 9½ per cent came from 17 more countries.

Almost the entire Canadian output comes from the serpentized peridotites of the Eastern Townships of Quebec, and as there are large areas of such rocks in India, Pakistan and Burma, which need further examination for asbestos, no excuse is needed for mentioning the Quebec occurrences here. The peridotites are associated with pyroxenites and occur as sheets and stock-like masses, mainly in a narrow, interrupted zone, intruding both Cambrian and Ordovician strata. The asbestos is of two types, cross fibre and slip fibre. The former occurs in veinlets with clean-cut walls, the fibres arranged parallel to one another and at a high angle or normal to the walls. Most of the output is of this variety. Slip fibre occurs in highly sheared serpentine, with the fibres more or less matted and lying lengthwise along the slippage planes.

The veins of cross fibre vary in width from a hairline to 3 inches, or very rarely to 4 or 5 inches. All the material over three-eighths of an inch is hand-selected and cobbled and is known as 'crude', but all the shorter material is milled, the rock being crushed, beaten and screened and the asbestos lifted from the screens by overhead suction. The milled variety amounts to more than 99 per cent of the total production. The walls of the veinlets consist of serpentine that passes rapidly at the edges farthest from the vein into the ordinary partly serpentized peridotite. We are indebted to an official publication of the Geological Survey of Canada for this information.

The serpentized peridotites of our areas should be minutely examined for small veinlets, which are easily overlooked on cursory inspection. Too much attention has been paid in the past to the length of the fibres, and the fact that 99 per cent of the Canadian output is from veinlets under three-eighths of an inch in width is a useful corrective to this idea. Commercial value depends less on length than on such properties as tensile strength, fineness, flexibility, colour, heat and electrical resistance. It may be added for the information of prospectors that the crocidolite and amosite

deposits of South Africa occur in bedded pre-Cambrian rocks associated with dolerite sills.

MICA

The micas form a group of complex silicates of aluminium and potassium, containing varying proportions of magnesium and iron in the dark varieties such as biotite; sodium, calcium, lithium, titanium, chromium and other elements may also be present. All the micas carry hydroxyl, which is commonly replaced to a varying extent by fluorine. All the micas are also characterized by their very perfect, basal cleavage which causes them to split into elastic, lustrous sheets of extreme thinness. Muscovite, or potash mica, with the formula $\text{KAl}_2(\text{AlSi}_3)\text{O}_{10}(\text{OH},\text{F})_2$, is the most valuable member of the group. The Bihar variety has a deep ruby colour, though this is not evident in thin sheets below one hundredth part of an inch in thickness. Phlogopite, or magnesian mica, a silicate of aluminium, magnesium and potassium, $\text{KMg}_3(\text{AlSi}_3)\text{O}_{10}(\text{OH},\text{F})_2$, is also used in industry for special purposes. Other members of the group include the black, or dark brown, ferromagnesian variety known as biotite, $\text{K}(\text{Mg},\text{Fe})_3(\text{AlSi}_3)\text{O}_{10}(\text{OH},\text{F})_2$, only used in the powdered form as a filler or coating, lepidolite, or lithium mica, a silicate of aluminium, potassium and lithium with hydroxyl and fluorine, $\text{KLi}_2\text{Al}(\text{Si}_4\text{O}_{10})(\text{OH},\text{F})_2$, a source of metallic lithium, and roscoelite, the vanadium mica, in which the aluminium of muscovite is replaced to some extent by vanadium.

Muscovite, though one of the commonest rock-forming minerals, is only found in the sizes and qualities demanded by the market in the pegmatite veins of a few restricted areas, for the most part in India, with smaller occurrences in Brazil and elsewhere. Phlogopite is derived mainly from Madagascar and Canada. Mica finds its chief use in the electrical industry as an insulating medium. For this and other purposes its perfect cleavage, enabling it to be split into sheets less than one thousandth of an inch in thickness, its transparency, flexibility, toughness, resistance to temperature changes and chemical decomposition, low thermal conductivity and high dielectric strength, render it unique and indispensable. Mica mining has progressed with the advance of electrical engineering, and by reason of its properties the great developments of electricity production, motor transport, aeronautical navigation and electronics have been made possible. All types of electrical machinery and appliances contain mica; from generators and motors of all sizes to the sparking plugs of aircraft engines; from power transformers to radio valves and condensers; from television transmitters to the ignition coils of motor vehicles; from telephones to the heater elements of domestic and industrial equipment.

Non-electrical uses of clear mica include the windows and peep-holes of ovens, stoves and furnaces; lamp chimneys and

canopies, goggles, and, in general, it is to be found in any situation where a transparent medium resistant to heat and breakage is essential. Scrap mica, after being finely ground, is used in corrosion-resisting paints, in laggings for boilers and steam pipes, as facings for moulds and cores in foundry work, as a filler for plastics and rubber preparations, as a lubricant in axle greases and oils, and as a surfacing powder to prevent sticking in rolls of tarred material such as roofing felts. Ground mica also has decorative value in the manufacture of wall-papers and is used to give a finish to plaster, stucco and concrete constructions. In India mica powder is used for dusting mica splittings during packing.

The total value of the mica yielded by the chief producing countries, India, Brazil (from 1936), Canada and the United States of America, during the first 39 years of the present century, 1900 to 1938 inclusive, was £21,430,149, and of this amount India alone was responsible for £17,073,369, or 79·6 per cent. Mica production statistics can be very misleading, as scrap material is included in the returns from some countries, but if dressed mica alone is considered, India supplies about 80 per cent of the world's demand.

India's total exports of mica between 1897 and 1950 totalled 262,968 tons, valued at £51,395,000 approximately. Over the decade ending in 1933 they averaged 3,947 tons and £590,258, compared with 2,704 tons per annum for the previous decade 1914-23. During the decade ending in 1943, the corresponding figures had risen to 9,427 tons and £1,240,691. The average annual tonnage and its value for the five years ending 1948 were 9,323 tons and £2,860,725. The record annual output of 18,093 tons was made in 1948.

Up to 1934 the exports consisted solely of block mica and splittings, but since then 'scrap' mica, also classified as 'ground', or 'waste', has appeared in the returns, in which it forms 26·7 per cent of the tonnage but only 0·9 per cent of the value over the decade ending 1943, the corresponding figures for block mica being 14·5 per cent of the tonnage and 42·1 per cent of the value and for splittings 58·8 per cent and 57 per cent, respectively. For the five years ending 1948, scrap mica accounted for 25·2 per cent of the tonnage and 0·6 per cent of the value, block mica for 11·2 and 30·9 per cent and splittings 63·6 and 68·5 per cent, respectively.

The share of the United Kingdom in the Indian mica trade has gradually fallen from the receipt of over three-quarters of the exports at the beginning of the century, to about one quarter in the quinquennium 1934-8, rising to about one third again over the decade ending 1948. The United States of America is now India's best customer, and over the same period her share of the export trade has risen from around 15 to over 63 per cent, for although the United States is the largest producer today when all classes of mica are taken into consideration, the country admittedly raises only a small fraction of its own requirements of high-quality sheet mica.

Statistics relating to the actual production of mica at the mines in India are not completely reliable. Such as they are, however, they show that over the decade ending 1943 Bihar accounted for 70·6, the territory now known as Andhra for 14·2 and Rajputana for 14·4 per cent of the output. The remainder came in small parcels from the Eastern States Agency, Mysore, Gwalior, the Punjab and the North-West Frontier Province, now in Pakistan. For the three years ending 1946, of the recorded production of 19,903 tons, Bihar yielded 69·5 per cent, Andhra fell to 11·4 per cent and Rajputana (Rajasthan) increased to 18·9 per cent. The reasons usually given to explain the excess of the export over the production figures are that the former include splittings made from material found in factory waste heaps, block mica recovered by resorting old mine dumps and mineral obtained by illicit mining.

There are many references in the Sanskrit classics to mica, and its common name in Hindustani, *abrak*, from *abr*, a cloud, or *abru*, the heavens, connects its lustrous character with its supposed celestial origin. The ancient Hindu writers distinguished four separate varieties and each was supposed to be possessed of magical medicinal properties. Apart from its uses in Materia Medica, however, mica has been employed in India from time immemorial, for ornaments, decorations and glazing, as well as by artists for their transparent paintings. It finds a place in the tinsel decorations of banners, *tazias* and umbrellas at festivals and weddings. Its powder is sprinkled on clothes, fans and toys, as well as being incorporated in the glazes of some forms of pottery, to which it imparts a pleasing sparkle.

The date of the commencement of mica mining in India is lost in the mists of antiquity, though aboriginal tribes such as the Labanas, Mahajins and Bandathis are known to have burrowed into the soft mica schists on the sides of the mica-bearing pegmatites of the Kodarma field of Bihar, in search of the mineral, for centuries. Such workings were described by Breton in 1826, Buchanan-Hamilton in 1838, Sherwill in 1851 and F. R. Mallet in 1874. More or less regular exports are believed to have commenced about 1884. Early European efforts to work the mines, a few years earlier, had not been successful, and indeed the first venture of F. F. Chrestien, the pioneer of modern mica mining in India, at Bairia, near Tisri, in 1888, proved a failure. Later ventures were more promising, and by 1894 mining was well established under his direction at Tisri, Bairia, Bhandari, Musnodi and Kodarma. By 1899, F. F. Chrestien & Co. were operating 110 mines, Raj Krishna Sahana 31, and W. R. MacDonald 28. The manufacture of 'splittings', a process which revolutionized the mica business, had been introduced before 1900, but these early European-owned mines showed little improvement on the ancestral methods previously followed. About 1910, modernization of mining began to take place and the Chrestien concern enjoyed continued prosperity.

In the meantime, other companies had taken up mica mining, amongst them being Sundermal's Indian Mica Supply Co., Messrs Tata & Co., Hoare Miller & Co., and Bird & Co. Ltd. After the first world war (1914-18), most of these firms left the business, leaving only two European companies, Messrs Chrestien's and J. Podger's, and the industry passed gradually into Indian hands, a process completed with World War II by the liquidation of the Podger Company and the sale of the Chrestien concern to Aggarwal Bros., by whom it is now controlled under the title Chrestien Mica Industries Ltd. Other companies include those managed by the Sahana Bros., the descendants of Raj Krishna Sahana; Messrs Chatturam Horilram and the Chota Nagpur Mica Syndicate (1932) Ltd.

The mica belt of Bihar extends from the Gaya district on the west for some 90 miles, through Hazaribagh and Monghyr, to the Bhagalpur district on the east, with a width of 12 to 16 miles. Its most productive portion lies in and around the Kodarma Reserved Forest. The country rocks are mica schists grading into mica gneisses, hornblende and quartz schists, while pegmatite veins, tongues and masses which penetrate them are the source of the greater part of the world's supply of high-grade muscovite. The veins usually strike and dip parallel with their enclosing schists and vary in thickness from a few inches to a hundred feet or more; though they may carry mica in profitable quantities for any distance up to 1,000 feet or so, the vast majority are short lenses up to 100 feet or thereabouts in length. Some of them are almost pipe-shaped, extending downwards for several hundreds of feet. The veins are formed of coarse aggregates of quartz and albite, with a little microcline in places and such accessories as tourmaline, garnet, apatite, and, more rarely, columbite-tantalite and beryl. The thicker veins almost always have quartz cores with the feldspar and mica contents arranged on either side of them. The mica occurs in the form of 'books', averaging 6 to 12 inches across and 3 or 4 inches thick, but, exceptionally, up to 3 feet or more in width and 2 or more feet in thickness. It is usually found along the sides of the veins, at or near their contacts with the country rocks, and the bearing zones do not as a rule exceed three feet in thickness, while tending to form 'shoots' of variable strike extension which pitch either vertically or very steeply downwards. As a rough approximation the mica contents may be said to range around 6 or 7 per cent of the total pegmatite excavated, but containing only 1.0 to 1.5 per cent of commercially valuable block mica.

At the present time there are about 600 separate mines on the Bihar field, including the shallow, surface, *uparchalla* workings (open-cuts and tortuous, winding holes in the pegmatites, following on from one mica 'book' to the next). About 100 properties, however, are now mechanized and the larger ones are developed systematically on sound mining principles. They are of varying depths down to 700 feet.

Mica mining commenced on a small scale in the Nellore district of Andhra about 1887 and at one time supplied upwards of 20 per cent of the total Indian production, though this has now fallen to about 11 per cent. The mica belt, which stretches for some 60 miles between Gudur and Sangam, has a width of 8 to 10 miles, with the mines located more or less on its margins and near Gudur, Rapur, Podalakur, Atmakur and Kavali, of which Rapur is the leading centre. According to A. Krishnaiya and B. C. Roy, the country rocks are Archaean schists of micaceous and hornblendic types, in which sheets, lenses and large masses of pegmatite are of frequent occurrence, striking north-west and south-east, or north and south, with the general foliation direction, and dipping steeply or vertically. They consist of very coarse intergrowths of quartz, orthoclase, microcline and plagioclase, with some tourmaline, garnet, apatite, beryl and sparse rare-earth minerals. Most of the region is flat and the rocks are normally hidden under a mantle of soil, which has led to mining in large open-cast excavations, but some mines, such as the Tellabodu and the Shah, are situated on hillocks. The mica books vary in size from a few inches to several feet across, and although great crystals of muscovite measuring 15 feet along the foliae and up to 10 feet across the basal plane have been obtained, such immense sizes are most exceptional. The average thickness of the pegmatites is from 10 to 15 feet and the majority of the individual, echelon lenses which build them do not exceed 100 feet in length, though a few carry payable mica values for several hundreds of feet. Most of the Nellore mica has a characteristic green tint, but some red mica similar to the 'Bengal Ruby' is also found. Many of the mines have reached a depth of 300 feet, while the deepest, the Shah, is about 630 feet below the surface.

Rajasthan, with almost 19 per cent of the Indian production to its credit during the period 1943 to 1946, now supplants Andhra for the second place in the list of producing regions, in which it first appeared in 1904. Its mica-bearing pegmatites are distributed over a belt of country some 60 miles wide, stretching from Jaipur in the north-east for upwards of 200 miles into Udaipur (Mewar) in the south-west. The north-western border of the main mining area follows the axis of the Aravalli Range; on the north-east it disappears under the blown sand and alluvium of Jaipur; to the south-east it keeps well to the north of the Banas river, except in the vicinity of Tonk city, while to the south-west it ends in the fringes of the Udaipur hills. Outside this main region are a few small, outlying areas in north Jaipur, and the Narnaul district of Patiala; in Alwar, Bharatpur, Delhi and Gurgaon; in the Bhomat district of the former state of Mewar and in Dungarpur.

The mica occurs in coarse granitic pegmatites which may be differentiated into quartz cores and feldspar-mica margins recalling those of the Bihar field. The accessory minerals include

tourmaline, apatite, garnet; more rarely, radio-active and rare-earth minerals and beryl, which is of considerable economic importance. The pegmatites themselves are intrusive into the rocks of the gneissic complex and into the Aravalli schists, and they vary enormously from a few inches in width and extending for a few feet, to great ridges 500 yards or so in length and up to 100 yards wide. Commonly, they form steeply dipping sheets following the general schistosity, but bosses, pipes, apophyses and branches also occur. The region is relatively flat compared with the Bihar field, but the pegmatites often crop out above the level of the surrounding country. The mica occurs sporadically in rich shoots, normally not more than 4 feet thick, and much of it is of the black-spotted variety, with perhaps 40 per cent of the total mica yield made up of the 'ruby' kind. This, unfortunately, is often stained, warped and cracked, so that on the whole only a small proportion of good quality block mica is obtained. These faults are expected to improve as the mines attain greater depth, for at present most of the workings are shallow and limited to depths attainable without the aid of pumping machinery.

On all three fields the books of crude mica are taken from the mines to the cutting sheds where they are rifted into slabs about $\frac{1}{4}$ -inch thick, which are then trimmed to remove flaws, a sickle being used for the purpose in Bihar and shears in Andhra. The product, now in slabs from $\frac{1}{10}$ to $\frac{1}{2}$ inch thick, is known as 'dressed block' and it amounts to 20 or 25 per cent of the crude mineral. The next process is the sorting of the dressed mica into the various market sizes, measured by the largest rectangle which will fit within the limits of the irregularly shaped block. There are ten or twelve of these sizes, ranging from No. 7, with an area of less than 1 square inch, to 'extra specials', with 80 to 100 square inches of area. After sizing comes the grading process with nine separate qualities, ranging in order of value from 'superfine', with no stains or flaws of any description, to the excessively stained varieties. Most of the larger sizes and better qualities are exported in block form. The poorer qualities of Size No. 5 (3 to 6 square inches) and lower are converted into splittings, which in recent years have formed over 60 per cent of the exports of all forms of Indian mica, including scrap. By means of a sharp pointed knife a piece of mica, perhaps 0.01 inch thick, is divided into splittings which are only 0.001 inch thick. Such splittings are graded for size, loose-packed for Size 5 and smaller; book-packed for Sizes 5, $4\frac{1}{2}$ and 4 (6 to 10 square inches), or pan-packed. These operations demand extreme delicacy of touch, as well as remarkable dexterity, and are usually done by women trained to the work from childhood. The pre-eminent position they have attained in this craft is shown by the fact that block mica and rough splittings are sent from other countries, such as Brazil and Madagascar, to India for processing and re-exportation in the form of fine splittings. For the ten years

ending 1933, such imports averaged 67 tons per annum. In the next decade, ending 1943, the average annual imports were much the same at 78 tons, but by 1946 they had risen to 553 tons of block mica alone, when the Government of India, acting in the interests of the Indian producers, interdicted the trade from Brazil. Mica splittings are utilized in the manufacture of 'micanite' or 'built-up mica', the individual films being cemented together with shellac or some synthetic adhesive. Such materials of any desired thickness can be stamped or moulded into any required shape, and the amount of built up mica made and used in this way today far exceeds that of block mica utilized in its original state.

Mica from Bihar and Rajasthan is marketed in Kodarma and Giridih, mainly in the form of 'mixed cut' and 'assorted block'. The splitting industry is chiefly controlled by large firms such as Chrestien Mica Industries Ltd, Chatturam Horilram, and The India Mica Supply Co. These, and other firms also, make mica washers and condenser plates. Nellore mica is exported from Madras by the South India Export Co., and by Chambers & Co. At one time most of the Indian mica was consigned to brokers in London who arranged for its re-distribution to consumers everywhere, but since 1928 the larger Indian exporters have shipped directly to their principal foreign consumers, now mainly in the United States of America. At the time of writing, 1951, mica is purchased by Indian representatives of American buyers against firm orders and on payment of 80 to 90 per cent of the invoice value; the balance being forthcoming after inspection in the United States.

The amber mica, phlogopite, occurs in association with pyroxenites near Neyoor and Punalur, in Travancore, but has not been successfully exploited. It has also been found in the Mugdula area of Visakhapatnam, and described by A. K. Dey from Borra in the Srungavarapukota taluk of the same district. Apart from the great mica fields of Bihar, Rajasthan and Andhra, muscovite has also been obtained from the Manbhum, Singhbhum and Palamau districts of Bihar. In Orissa, poor-quality material has been mined in Sambalpur, Angul and Dhenkanal, and recorded from Ganjam, Koraput and a number of localities in western Orissa, as well as from various places in the territories formerly known as the Eastern States Agency. The Cuddapah district of Andhra and the Salem, Malabar and Nilgiri districts of Madras have all supplied small specimen parcels, while M. S. Krishnan has described the deposits of the Tiruvur taluk of the Krishna district. Muscovite plates up to 6 inches in diameter have been found recently by Dey and Srikantan 2 miles south-west of Mercara, in Coorg. Similar, rather spotted and stained mineral is known to occur near Srimangalam and other places. Small amounts of muscovite have also been obtained from the Hassan and Mysore districts of Mysore and from the Midnapore and Bankura districts of West Bengal. Books of mica, half an inch thick and up to 4 or 6 inches

in diameter, of a pale green colour, but exhibiting strain effects, occur, with small quantities of beryl, in lenticular veins of quartz and feldspar, traversing finely foliated micaceous rocks, near Giddarpur, Mansehra *tahsil*, Hazara district, North-West Frontier Province, West Pakistan. Muscovite has also been reported from a number of localities in Chitral. Small quantities of mica, probably phlogopite, have been obtained from Yenya U, near Thabeitkyin, in the Katha district of Upper Burma, but it is doubtful if this occurrence is of any commercial value.

The vital strategic necessity for mica led to a number of special war-time developments which included the authorization, in 1940, of the Geological Survey of India to supply the requirements of the United States of America; the establishment of an Indo-American Mission in Calcutta, in 1942, to procure the supplies of the Allied Powers; the formation of the Mica Production Sections of the Geological Survey of India, with their headquarters at Kodarma, Gudur and Ajmer; the operation by the State of mica mines in the Monghyr district of Bihar, and the erection of a Government Mica Factory at Pachamba, in Bihar. The results of these and other measures are reflected in the greatly increased exports of later years, detailed in the table on p. 549. With the end of World War II, in September 1945, and the termination of the activities of the Joint Mica Mission in India, there was naturally, during 1946 and 1947, a temporary lull in the Indian mica industry. Afterwards, however, as the stock-piling programme of the United States gathered momentum, the American demand increased, only to slacken again after May 1951, though it was compensated to some extent by better orders from the United Kingdom, while the appearance of France, Switzerland, Germany, Italy, Belgium, Czechoslovakia, and Japan as buyers gave an upward trend to the market. Indeed, by the middle of the year 1951, the prices of block mica, especially of the spotted variety; of first-quality, ordinary, loose splittings and of No. 6 loose dust, had risen between 200 and 300 per cent above the prices in vogue during the time of the Joint Mica Mission. The boom did not last long; the inclusion of parcels of substandard quality, resulting in the suspension of American purchases, was a blow to the industry, in which all its branches suffered equally. It emphasizes the necessity for some system of inspection, control and guarantee by State agency, if such violent fluctuations are to be avoided, and if the would-be buyer is not to be driven to seek more reliable sources of supply.

Mica mining in India suffers from a legacy of indiscriminate shallow, surface working, handed down from earlier generations and harmful not only for the waste inherent in it and the lack of records, but also for its obliteration of surface indications. The industry is also plagued by the illicit trader and his confederate in the mines themselves, but the enactment of the Bihar and Orissa Mica Act in 1932, the Mica Control Order of 1940, and the appointment

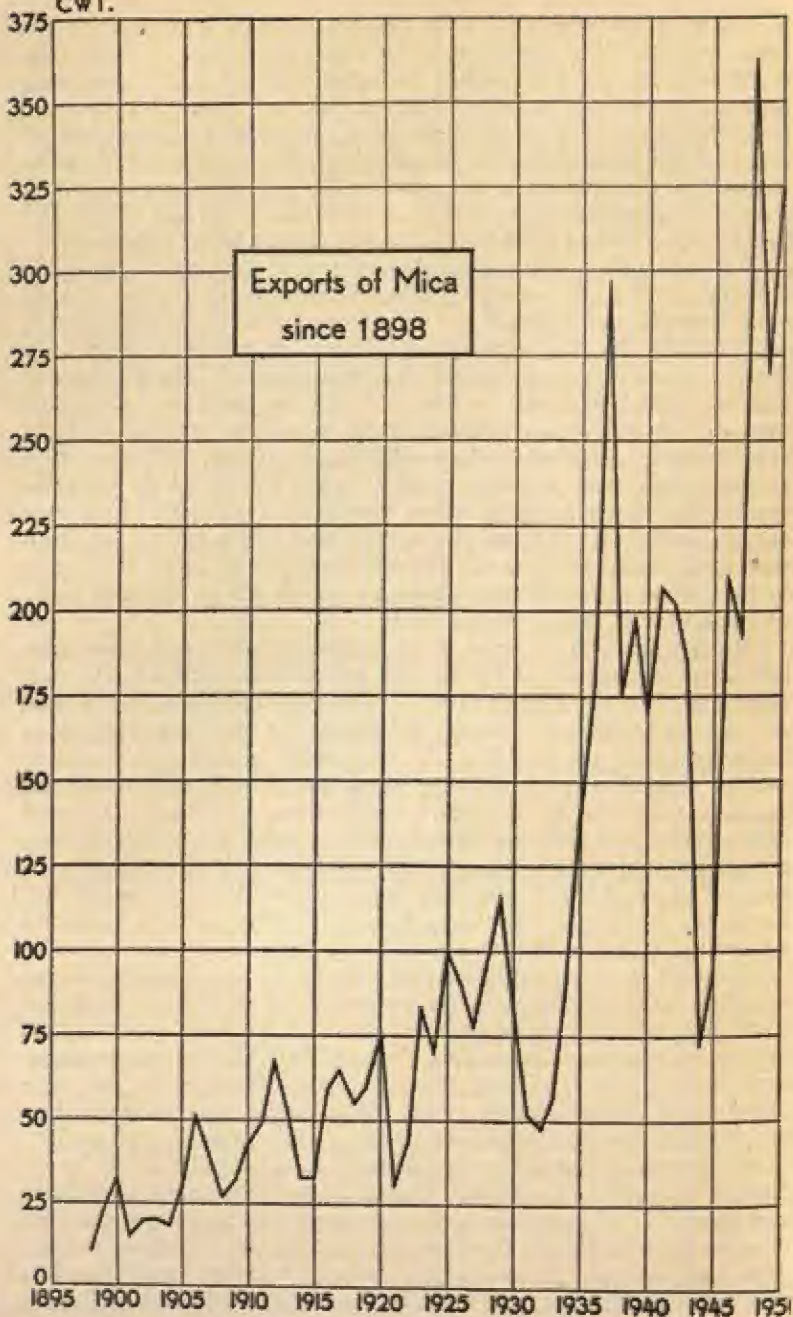
of a Mica Controller with wide powers in 1945, demonstrate the determination of the authorities to deal with these abuses. At the same time, the wellbeing of the labour force has not been overlooked, for the Mica Mines Labour Welfare Fund Act of 1946 provides for the levying of a cess of $2\frac{1}{2}$ per cent *ad valorem* on all exported mica, to form the foundation of a fund which is to be devoted to the welfare of the mica workers themselves, of whom there are estimated to be from 50,000 to 60,000 in the mines and factories as well as a further 100,000 engaged as home splitters.

For the proper planning of future development, systematic drilling is essential to determine the extensions of the pegmatites both laterally and in depth. The reserves of the three major fields are undoubtedly very great, but proper exploitation at greater depths demands both technical skill and capital. The haphazard methods of the past will no longer avail; the heyday of the small man, or the individual villager turned miner, is passing, if India is to retain her position in the world's mica market. That position at the present time depends largely on the ability of the trade to produce splittings cheaply, and as long as that is possible by means of a contented labour force, the competition of the synthetic substitutes for micanite, such as the silicone plastics, intensively developed in the United States of recent years, can doubtless be met and India will continue to dominate the trade.

Block mica will continue to be in demand, for pure sheet mica has some properties which cannot yet be matched by any one substitute; but the Indian producer should remember that as soon as research develops a perfect substitute, or succeeds in making larger synthetic crystals than those already produced in the laboratory, it will only be relative cheapness which will retain his markets, and, even so, strategic considerations will lead to support being given, by the Governments of consuming countries, to indigenous industries whose supplies are not liable to interruption in the event of war. In this connexion he should also bear in mind that Brazil is a growing competitor of India, and that much American capital has been invested in the industry there.

In their own interests, Indian producers must establish and maintain a reputation for consistency of quality. Tentative standards for the grading and classification of mica were drafted by the International Standards Organization Committee at meetings held in New Delhi in January 1950. Grading in the mica trade concerns the sorting of the mica pieces according to their size, while classification involves visual determination of quality. It is understood that the proposals are now under discussion by the Indian Standards Institute. Unless some system of inspection and control is adopted, however, to enforce whatever specifications may be decided upon, they are likely to remain little more than pious aspirations. It is for this reason, together with the fact that any classification will be complicated, that the establishment

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of a marketing system, such as that recommended by the Mica Enquiry Committee in 1946, or perhaps of separate Regional Marketing Boards, with centralized testing and grading facilities, is essential for the orderly expansion of the industry in the future. A mineral industry capable of supplying all the country's own needs for an indefinite time to come, and at the same time in a position to dominate the world's markets and earn large credits by its export trade, which in 1951 alone were worth more than Rs 9 crores, deserves all the protection and assistance which the supervision of the State alone can ensure.

There is also much scope for the manufacture of built-up mica products in India, and for the profitable utilization of the scrap mica from the huge mine dumps and the rejected waste from the factories. Though it is desirable to substitute for shellac a more stable bonding material such as a silicone varnish, in the manufacture of micranite, or even to use pulverized mica as a filler in a plastic moulding-powder, the development of suitable synthetic resins in India cannot be expected for some years, by which time it may be more economical to manufacture wholly synthetic insulating materials to meet specified requirements. The commanding position held by the country in the mica trade of the past and the manual perfection attained by its splitters, are not good reasons for relaxation of effort to improve and extend mining methods, or to delay the introduction of finishing processes now successfully carried out in other lands.

EXPORTS OF INDIAN MICA, 1897-1950

PERIOD	QUANTITY	VALUE	DESTINATION		
			United Kingdom	United States of America	Germany
	tons	£	%	%	%
1897-1902* ..	5,751.9	465,678	77.4	15.5	5.4
1903-7* ..	8,151.25	827,016	52.8	14.7	22.7
1908-13* ..	13,614.20	1,322,486	55.4	16.9	16.1
1914-18* ..	12,396.55	1,915,073	Restricted to the United Kingdom		
1919-23 ..	14,650.0†	3,166,655	53.2	37.5	4.8
1924-8 ..	21,635.4	3,689,651	40.6	37.2	12.0
1929-33 ..	17,834.4†	2,212,933	41.3	32.4	8.1
1934-8 ..	44,242	3,647,033	25.9	49.3	10.3
1939-43 ..	48,234	8,759,885	32.0	58.5	..
1944-8 ..	46,615	14,303,624	34.4	57.5	..
1949-50 ..	29,843	11,085,550	27.3	63.4	..

GRAND TOTAL, 1897-1950 (inclusive), 262,968 tons, valued at £51,395,584.
(Reckoning the rupee as the equivalent of one shilling and six pence for the years 1934-50.)

* Fiscal years.

† Figures for 1921 represent 9 months only.

‡ Divided as to 83.2 per cent splittings and 16.8 per cent block mica.

VERMICULITE

Muscovite mica is one of the least alterable of minerals and its unchanged scales can be found in granites which have been completely kaolinized by hydrothermal agencies. Biotite and phlogopite, on the other hand, alter their composition easily and pass into the group of minerals known as the vermiculites, through hydration and loss of their alkaline contents. 'These compounds', wrote F. W. Clarke, 'form a series intermediate between the micas and the chlorites and mark a transition into the latter group of minerals.' Some mineralogists, however, classify the tubular, radiating and granular types of vermiculite and ripidolite as members of the chlorite family. The vermiculites form soft, pliable and inelastic laminae, with a pearly or bronzy lustre, and they vary in colour from white to yellow and brown. On ignition they lose water, swell and exfoliate, sometimes into worm-like threads, from which they derive their name. The appearance of the heated mineral has also been described as possessing an accordion-like form, and the expansion which it undergoes may be up to ten times its original volume, while it may then weigh as little as 6 to 8 lb. per cubic foot. This property is probably due to the presence of layers of molecular water which lie between the other layers in its internal structure.

It is on this property that the economic importance of vermiculite depends, and in the expanded form it is widely used for thermal and acoustical insulations, in any situations where they may be required. Combined with bonding agents it is employed in plasters and in laggings for hot or cold pipes and for boilers; mixed with concrete it is used in many forms in building construction, particularly for pre-cast, light-weight slabs, roofing tiles and fire-proof interior walls.

Expansion plant for the treatment of vermiculite has been erected in India by Burn & Co. Ltd at Raniganj, where materials for the insulation of both heat and sound, for domestic and for industrial use, are manufactured from imported mineral. Further work is needed on the indigenous occurrences to determine whether they are not capable of meeting existing requirements which, if the experience of other countries is any guide, are likely to increase rapidly.

A brownish-green variety occurs in fairly thick beds in mica mines 10 miles west of Gudur, Nellore district, Andhra. On heating it is said to expand 11 or 12 times in volume and to assume a lustrous, coppery-brown colour. Small bands and lenticles of flaky, bronzy vermiculite were found by B. C. Roy, associated with basic and ultrabasic rocks and mica schists, intruded by pegmatites and quartz veins, near Gudas, in Ajmer-Merwara. This mineral swells up to 8 times its original volume on heating. From the Hassan district of Mysore, B. P. Radhakrishna has reported about 5,000 tons of the mineral at Malavanghatta,

with a further 1,000 tons at Bageshpur, but these reserves are too small to be of much service. Other occurrences are known near Koratagere and Nidavanda, Pavagada taluk, Tumkur district, Mysore; at Kamasamudram near Bangarpet, Kolar district, and from Channarayapatna and Chunchankatte, in the same State. The mineral has been recorded in the Bankura district of West Bengal, but in none of these cases are there any estimates of the available quantities. The first official record of the production of vermiculite in India appeared in 1950 when 52 tons, valued at Rs 1,620, were reported from the Kolar and Hassan districts of Mysore. In 1951 the output had increased to 232 tons, valued at Rs 6,352.

The largest known deposits of vermiculite are in Montana, United States of America, and in the Palbora district of the Transvaal, South Africa, but it is also won in other countries, including Australia and East Africa. The annual production in the United States increased from 60,000 tons in 1936 to over 117,000 tons in 1947. The South African production in the latter year was over 14,000 tons.

FULLER'S EARTH

The fuller's earths are soft, light greyish, greenish or brownish clays with a waxy appearance, soapy feel and less plasticity than the potter's or the ball clays. Some varieties, it is stated, consist predominantly of montmorillonite, the hydrated aluminium silicate, $\text{Al}_2\text{Si}_2\text{O}_{10}(\text{OH})_2 \cdot n\text{H}_2\text{O}$, in which magnesium may replace part of the aluminium, but the ultimate mineral composition of the Indian examples has still to be determined and it is best, in the meantime, to regard them as chiefly hydrated silicates of aluminium with variable amounts of magnesia, lime, alkalis and iron, together with a large water content. They possess the power of absorbing greasy matter and owe their name to their former use in fulling, that is in the scouring or cleansing of cloth. They are still widely used in India and Pakistan as detergents for washing clothes, and they also form part of the edible earths and medicinal clays obtainable in Eastern bazaars. Such earths are used on a large scale in the clarification of mineral and vegetable oils, from which they remove objectionable colours and other impurities. They are also employed in the paint and colour trades, as ingredients of soap, fillers of paper, and, in both the raw and burnt forms, in the manufacture of refractory cements.

The production of fuller's earth is increasing in India, the growth of the annual average tonnage being as follows: for the period 1924-8, 3,169 tons; 1929-33, 7,621 tons; 1934-8, 8,424 tons; 1939-43, 10,339 tons; 1944-6, 11,241 tons. Following the division of the country in 1947, the fuller's earth deposits of Sind and Khairpur passed to Pakistan, where the average annual output

for the three years 1947 to 1949 was 4,965 tons, two-thirds of which came from Khairpur and the rest from Sind. The annual average for India for the same three years (1947-9) was 4,565 tons, all of which, excepting 36 tons from Madhya Pradesh, came from Rajasthan in the following proportions: Jodhpur, 61.4 per cent; Bikaner 36.3 per cent and the remainder from Jaisalmer.

Sind (including Khairpur) and Rajasthan have long been the chief sources of supply: thus, over the decade 1934 to 1943, 62 per cent of a total Indian production of 93,817 tons came from Sind and 37.5 per cent from Rajasthan, with the small remainder from Madhya Pradesh. The Sind output was about equally divided between Sind proper with 28,851 tons, and the Khairpur State with 29,290 tons. Curiously enough, the Rajasthan production was divided in the same way between Bikaner with 17,076 tons and Jodhpur with 17,116 tons, Jaisalmer forming a poor third with 938 tons.

Many occurrences of fuller's earth are known in Sind, especially in the Sukkur, Hyderabad and Dadu districts, usually in bedded deposits associated with limestones of Khirthar age. The Rajasthan product—the well known *Multani matti*—is a yellowish, unctuous clay of Nummulitic age, which is quarried at Mar, near Kolaith, in Bikaner, and in the neighbourhood of Barmer and Kapuri, in Jodhpur. Near Palana, in Bikaner, seams of fuller's earth, 6 feet in thickness, have been worked by underground methods. In Jaisalmer there are 580,000 tons at Manda, 30,000 tons at Mandai and 20,000 tons at Bandah according to D. R. S. Mehta. The Rajasthan earths before the partition of the country in 1947 were sent to Multan and other cities now in Pakistan for distribution. The Madhya Pradesh material is derived mainly from rocks of Lower Vindhyan age, in the vicinity of Katni, in the Jabalpur district. Hyderabad (Deccan) possesses deposits in the Chincholi taluk of the Gulbarga district, where the clay was formerly used for fulling cloth and is now widely employed as an ingredient of soap, and as a purifying agent for vegetable oils. Lithomargic clays which occur about $2\frac{1}{2}$ miles west of Lakhanka in Bhavnagar are shipped to Bombay where they are processed into activated fuller's earths by the Bombay-Sewree Chemical Manufacturing Co. Ltd, according to B. C. Roy. Clays of a similar character are obtainable from various places in the lateritic zones of Nawanagar, Junagadh and other parts of Saurashtra as well as from Kutch. The demand for such materials is likely to increase now that two oil refineries have been constructed on Trombay Island, Bombay.

BENTONITE

The name bentonite was originally applied to a colloidal type of clay of Cretaceous age found in Wyoming, in the United States

of America. Since the original discovery in 1888, further deposits, from a few inches to several feet in thickness, have been found in California, New Mexico, South Dakota, Texas and in other regions, as well as in Alberta and Manitoba, Canada. True bentonite has been formed by the alteration of volcanic ash deposited under marine conditions and is said to be composed largely of the hydrous aluminium silicate, montmorillonite, and a closely related mineral, beidellite. Bentonite possesses the property of absorbing large quantities of water and of swelling greatly in the process. With more water it forms a gelatinous paste and in thin, watery solutions it remains suspended for a considerable length of time.

The term has been extended, however, and now is used to cover other types of clay which exhibit such properties to a much smaller extent—materials which absorb but little water, do not swell noticeably, settle quickly in thin dispersions and generally approach the fuller's earths in physical characteristics. They are sometimes referred to as the metabentonites. Between these extremes there are many gradations so that, as J. A. Dunn advised, actual small-scale tests are the best means of deciding whether any supposed 'bentonite' can be used for some particular process.

The commercial importance of the bentonites can be appreciated from their wide use in the United States of America, where 764,000 tons were produced in 1947. Nine-tenths of this tonnage was consumed in the petroleum and foundry industries—31 per cent for rotary mud drilling, 32 per cent for the filtration and decolorization of oils, and 27 per cent as a bonding agent for foundry moulding sands. Bentonite also enters into the composition of some forms of high-temperature refractories and electrical porcelains.

Bentonite, or a colloidal substance closely resembling it in properties, is reported to form a continuous bed, two feet in thickness, in gently dipping conglomerates of Siwalik age, and to extend for several miles, near Bhunber and Rattanpur Sarrara, in the Mirpur district of Kashmir, where it was originally worked by State agency before being taken over by private enterprise. Experimental parcels have been sold for oil-well drilling, petroleum refining and foundry use. The mineral is also won by State agency at Hathi-ki-dhani, in the Sheo *pargana* of Jodhpur, Rajasthan. It has also been obtained from Karauli, in Rajasthan, and is known to occur at Tinpahar, in the Santal Parganas of Bihar. From 1944 to 1950, 1,116 tons of bentonite appeared in the Mineral Returns, valued at Rs 16,058, of which 825 tons came from Jodhpur, 96 tons from Karauli and 195 tons from Kashmir.

Indian bentonites have been successfully used in the oilfields as admixtures to drilling muds, the efficiency of which is enhanced by their thickening and wall-sealing properties. They have further useful fields of application in many problems of civil

engineering, where water percolation is undesirable, as well as in cement manufacture, in ceramics, and as spreading, filling, binding and emulsifying agents generally.

FLUORSPAR

Fluorspar, or fluorite, is the natural fluoride of calcium, CaF_2 , a rather soft mineral, usually found in the form of cubes which possess a perfect, octahedral cleavage, but also in compact and granular forms. Its colour range is wide, ranging from clear, transparent, colourless varieties to many shades of green, blue, yellow, amethyst and purple. Transparent, flawless crystals bring premium prices in the optical industry, for use in the manufacture of special lenses for telescopes and microscopes as well as prisms for spectrographs. The massive, dark blue and purple varieties have been used for vases and other ornamental purposes.

The mineral fuses very easily, a fact to which it owes its name and a great part of its industrial importance as a flux for metallurgical purposes, notably in the production of steel and aluminium. It is consumed in large quantities in the basic, open-hearth manufacture of steel, being added to the bath before the furnace is tapped, to increase the fluidity of the slag and to assist in the removal of objectionable impurities such as sulphur and phosphorus. Every ton of steel made by this process is said to require from 6 to 8 lb. of fluorspar. Smaller amounts are also needed in the manufacture of electric furnace steel, ferro-alloys and in iron-foundry operations. Of an annual world production in pre-war years of approximately 400,000 tons, now probably increased to over half a million tons of fluorspar per annum, it has been estimated that in recent years about 65 per cent was used in steel and iron metallurgy.

Fluorspar is the source of many fluorine compounds, an outlet which probably ranks second amongst its many applications. Fluorine itself, a pale yellow gas at ordinary temperatures, obtained on a commercial scale by the electrolysis of molten potassium hydrogen fluoride, and probably the most active element known, is a very powerful oxidizing agent. Hydrogen fluoride, H_2F_2 , or in aqueous solution, hydrofluoric acid, made by the action of sulphuric acid on fluorspar, is used for etching glass, clouding electric light bulbs and cleaning and pickling metals and wires, but a more important use is as a catalyst in the low-temperature alkylation of paraffin hydrocarbons and the production of aviation spirit. Amongst its inorganic compounds are boron trifluoride, BF_3 , used as a catalyst in the preparation of esters and in the polymerization of the olefine hydrocarbons into oils and gasolines; lithium fluoride, LiF , used in fluxes for soldering aluminium and as a substitute for optical fluorite; ammonium fluoride, NH_4F , utilized in the manufacture of artificial cryolite,

and sulphur hexafluoride, SF_6 , a colourless, inert gas, finding wide employment as an insulator in high-voltage electrical and X-ray work. Antimony trifluoride, SbF_3 , cobalt trifluoride, CoF_3 , and the trifluorides of chlorine and bromine are vigorous fluorinating agents widely used in organic chemical processes. Some of the complex salts formed from antimony trifluoride and the fluorides of the alkali metals have their uses in dyeing. It has recently been established that children living in regions in which the natural waters contain appreciable amounts of soluble fluorides suffer less from dental caries than those of other areas, and in the United States of America and the United Kingdom (on an experimental scale), fluorides are now added in small quantities to the drinking water supplies to control this disease.

Certain organic compounds of fluorine have lately assumed much industrial importance: amongst others are the fluorochloromethanes and -ethanes, known in Britain as 'arctons' and in America as 'freons', which are said to be amongst the most inert organic compounds known; difluorodichloro-methane, or freon 1.2, has the formula CF_2Cl_2 and both it and related compounds are used on a large scale as air-conditioning and refrigerating media, as well as in fire extinguishers and in pyrethrum and sesame oil, aerosol bombs for the extinction of malaria and yellow-fever mosquitoes. Tetra-fluoroethylene, C_2F_4 , is a colourless gas which polymerizes easily into a dense, white, crystalline solid which is chemically inert, thermally stable and possesses a low dielectric constant. It and related compounds are used in insulation and in chemical plant for valve packings, gaskets, etc. It is marketed in America under the trade name 'Teflon' and in Britain as 'Fluon'. By the polymerization of fluoro- and fluorochloro-olefines, according to Hazeldine and Sharpe, in their account of 'Fluorine and its Compounds', published in 1951, from which some of these details are taken, it is now possible to produce on a commercial scale, oils, greases and solid polymers, while polymers of other compounds yield translucent and transparent plastics.

The preparation of many of the aromatic (closed chain) organic compounds of fluorine involves the use of benzotrifluoride, now made in Britain by the Imperial Smelting Co. Ltd. Such aromatic compounds are used extensively in the dyestuffs field for wool, silk, nylon and cellulose acetate.

'The chemical and thermal stability of the fluorocarbons,' write Hazeldine and Sharpe, 'make them useful as coolants, sealing liquids, reaction and dielectric media and high temperature lubricants in specialized equipment, such as in the recoil mechanism of large guns and in apparatus involving the vigorous fluorinating agent uranium hexafluoride.'

Apart from its uses in metallurgy and as a basis material in inorganic and organic chemistry, fluorspar has many other outlets. Thus it is used to facilitate fusion of the materials in the

manufacture of calcium carbide and cyanamide; in the extraction of potash salts from feldspar and the flue dust of cement kilns; as a bond for abrasive wheels and carbon electrodes; in welding rod coatings and in the glass, ceramic and enamelling industries.

Though it is widely distributed in small quantities, especially in association with the ores of lead and zinc, workable deposits of fluorspar are rare and only one that can be so described has been discovered in India. Traversing the borders of Nandgaon and Khairagarh, about 14 miles from Dongargarh, Madhya Pradesh, is a series of low ridges striking north and south and extending at intervals for about 12 miles. These are formed by quartz veins of pegmatitic origin, up to 60 feet in width, developed along a narrow shear zone in granite. They contain sporadically scattered grains of galena and pyrite with fluorspar, particularly at Chandi *Dungri* and Kotnapani, where they average 26 to 30 per cent of fluorspar. The estimated reserves, to a depth of 60 feet, are of the order of 104,000 tons in Khairagarh and 46,000 tons in Nandgaon. Between 1939 and 1946 approximately 9,000 tons of fluorspar were taken from the Khairagarh deposit, including 1,229 tons in 1944 and 431 tons in 1945.

Several quartz veins carrying fluorspar, including one with an average width of 30 feet, traceable on the surface for 7,000 feet, exist at Churakuta, Ghatkachhar and Makarmuta, in the Mahasamud *tahsil* of the Raipur district, Madhya Pradesh.

The quartz-calcite-fluorite veins in gneiss at Barla, Kishangarh, Rajasthan, have been investigated by the Tata Iron & Steel Co. with disappointing results. Other occurrences, perhaps of more mineralogical interest than economic importance, include the violet crystals associated with quartz, calcite and barytes in shear zones of limestone, at Malhar, Murwara *tahsil*, Jabalpur district, Madhya Pradesh; the presence of the mineral with lead and copper ores at Sleemanabad, in the same district; the small quantities found in the Bhandar Limestone of Rewah; the crystals from Mitagasht, in Chitral (Pakistan) and Wangtu, in Kangra, as well as the colourless varieties of the wolfram-bearing quartz veins of Tavoy, Burma, and Degana, in Jodhpur, Rajasthan.

As the output of Indian steel has grown, the imports of fluorspar have increased from 300 or 400 tons annually, during the years 1909-13, to upwards of 1,500 tons per annum at the present time, the Tata concern alone taking over 10,000 tons between 1934 and 1943. With the coming expansion of the steel and aluminium industries, the demand for fluorspar will be much greater, to say nothing of the chemical and other purposes for which it will become desirable.

Most of the principal steel-producing countries possess their own fluorspar resources, but, unfortunately, this does not yet apply in the case of India, where efforts must be made to free her

from dependence on imported supplies of a strategic mineral. The search for fluorspar demands a high priority: although normally an easily recognizable mineral owing to its wide colour range and crystalline form, this is not always the case, and valuable deposits have sometimes passed unrecognized for years in other lands. The systematic underground exploration of known deposits, such as those of Khairagarh and Nandgaon, is also necessary before their potentialities can be properly assessed. Should these prove large enough in depth, the milling, concentration and preparation of the ore into grades suitable for metallurgical, chemical and ceramic uses can be considered.

India possesses another potential source of fluorine in the apatite deposits of Bihar and elsewhere and in the minerals of the fluorapatite group contained in the phosphate deposits of South Arcot and Pondicherry. When these come to be developed for the manufacture of phosphatic fertilizers, attention should be directed to the recovery of fluorine-bearing byproducts during their processing.

MAGNESIUM CHLORIDE

The chloride of magnesium, $MgCl_2$, is used chiefly as a sizing agent in textile mills where all warp yarns before being taken to the looms are passed through sizing mixtures, to keep them soft and pliable, to increase their strength and weight and so enable them to offer greater resistance to wear and tear than would otherwise be the case. The hygroscopic character of magnesium chloride makes it a particularly suitable ingredient of textile sizes, which may in addition contain other materials such as flour, tallow, starch, china clay, zinc chloride and magnesium sulphate. The consumption of magnesium chloride in India varies greatly at different textile centres; thus in the dry and hot climate of Ahmedabad much more is used than in Bombay, for example. The compound is also used in the dressing and filling of cotton and woollen fabrics, as a lubricant in calico weaving and in dyeing.

Besides its applications in the textile industry, magnesium chloride is used, in combination with magnesia, to make the oxychloride cements of the building trade which are referred to under MAGNESIUM, and most of the foreign demand for the Indian product is believed to be for this purpose. Solutions of the salt are employed as refrigerating media and it is also used for fire-proofing wood, in fire-proof paints and fire extinguishers, in the treatment of mine timbers and in preparations for laying dust on roads, in addition to many further minor purposes.

Before the first world war (1914-18), the manufacture of magnesium chloride was to all intents and purposes a monopoly of Germany, where it was recovered from the carnallite deposits of Stassfurt, carnallite being the natural hydrated chloride of potassium and magnesium, $KCl.MgCl_2.6H_2O$. Indian imports

of the substance ceased with the outbreak of this war and attention had to be directed to home resources, as the mineral was known to exist in the bitters of the salt works at Kharaghoda, on the Little Rann of Kutch, and in those of Kuda, 10 miles away, in Dhrangadhra. The Government of Bombay invited tenders for the right to remove the Kharaghoda bitters from the official salt works in 1916, and the successful production of magnesium chloride was inaugurated by the Pioneer Magnesia Works, a private concern which owed its origin to the enterprise of B. S. Lalkaka. Space does not permit a summary of the development of the industry, its early successes, its difficulties in the export trade, its struggles with the revival of German competition and its appeals to the State for protection. It must suffice to mention that the Mayurdhwaj Magnesia works at Kuda, in Saurashtra and those of Tata Chemicals Ltd at Mithapur, 7 miles from Okha, a Bombay enclave in Saurashtra, both commenced to make magnesium chloride in 1932. From 1916 to the end of 1947, a total of 137,679 tons had been produced, of which 83.5 per cent came from Kharaghoda, 9.5 per cent from Mithapur and 7 per cent, approximately, from Kuda.

As early as 1920, small, trial consignments had been well received in the United Kingdom, but shipping difficulties, increased later by renewed German competition, hampered the development of the export trade which really only commenced in 1926. From then to the end of 1947, 28,941 tons had been shipped abroad by the Pioneer Magnesia Company. Of the 17,451 tons exported by that concern between 1937 and 30 April 1948, 67.3 per cent was destined for Great Britain, 17.2 per cent for Holland, 6.6 per cent for Australia, 6.4 per cent for Scandinavian countries, 1.4 per cent for Czechoslovakia and 1.1 per cent for South African ports. The total capacity of the industry is 15,000 tons per annum—10,000 tons at Kharaghoda, 3,000 tons at Mithapur and 2,000 tons at Kuda, while before the last war the home demand was about 4,000 tons annually, though this was halved for the time being by the Cotton Textiles Sizing and Filling Order of 1942. A large surplus is thus left for export.

Valuable by-products are now also manufactured including magnesium sulphate, potassium chloride, potassium bromide and bromine, as well as various other chemicals. At Kharaghoda, the bitters from the salt works, themselves drawing brines from wells some 20 feet deep, are exposed in shallow ponds to solar evaporation for 8 days before transference to the boiling pans, where a white, waxy material is obtained which, after solidification and cooling, forms the 'fused magnesium chloride' of commerce. The remaining sludge, when mixed with water and allowed to stand in troughs for 4 days, yields magnesium sulphate (Epsom Salt). The final mother liquor is returned to the storage ponds. The commercial 'crystal magnesium chloride' is

obtained by baling out the strong solution from the boiling pans and allowing it to crystallize slowly. By mixing the concentrated bitterns with soda ash, and exposing for some days to the air, magnesium carbonate is obtained, a compound which is used as a filler in the rubber industry and in the manufacture of boiler lagging. Calcium chloride, magnesium bromide and bromine are also made at these works.

Salt from the Kuda works is supplied to the alkali works at Dhrangadhra, where about 50 tons of soda ash and 5 tons of calcium chloride are made daily. After the recovery of about 60,000 tons of *baragra* salt from the Rann brines, some 1,800 to 2,000 tons of magnesium chloride are made annually at Kuda by methods similar to those used at Kharaghoda.

At the Mithapur works, according to K. H. Vakil, sea water is the starting point instead of the underground brines of Kharaghoda and Kuda which, as the analyses given on p. 560 show, have smaller amounts of potassium chloride and magnesium bromide. The sea water gains access to the shallow lakes and reservoirs through sluice gates operated automatically by the tides, and travels for 7 miles through them and their connecting channels while undergoing solar evaporation. The salt pans themselves are so designed that their bitterns gravitate naturally to a central pumping station whence they are delivered to the factory, where, cooled by refrigeration, they deposit a crop of 'commercial magnesium sulphate'. Further evaporation yields mixed salts containing kieserite, the hydrated magnesium sulphate, $\text{MgSO}_4 \cdot \text{H}_2\text{O}$, and potassium chloride, sylvite, KCl , while from the residue commercial magnesium chloride is obtained, and during this final operation bromine is evolved. By the use of specially designed plant, mixed salts containing carnallite, the hydrated chloride of potassium and magnesium, $\text{KCl} \cdot \text{MgCl}_2 \cdot 6\text{H}_2\text{O}$, and kieserite are obtainable, and the former, under properly regulated conditions, yields potassium chloride and a solution of magnesium chloride. The quantities of the various salts recovered from sea water at Mithapur over the years 1943 to 1948 are given below:

PRODUCTION OF SALTS FROM SEA WATER AT MITHAPUR,
(long tons), 1943-8

	Bromine	Epsom Salt	Potassium Chloride	Magnesium Chloride	Common Salt
1943-4	22	435	22	485	24,000
1944-5	2	538	46	477	36,000
1945-6	14	215	83	1,981	41,000
1946-7	17	277	44	1,400	36,000
1947-8	25	351	26	1,613	63,000

Around these works a heavy-chemical industry has grown up since 1939, the local coral reef being used to supplement the products obtained from sea water. In 1953-4 the Tata Chemical Works at Mithapur had a daily output of 125 tons of soda ash, 20 tons of caustic soda, 7 tons of chlorine, 20 tons of magnesium chloride, $\frac{1}{2}$ ton of bromine, $\frac{1}{2}$ ton of potassium and other bromides, 3 tons of Epsom salt, 7 tons of hydrochloric acid, together with some other products.

In so far as magnesium chloride itself is concerned, the supplies of raw material are unlimited, the manufacturing processes are simple and require no elaborate machinery involving the employment of expensive, skilled labour. There appears to be wide scope for its further development, though in normal times severe competition is likely from Germany, Japan and Palestine.

ANALYSES OF BRINES

	Rann brine at Kuda	Brine concentrated from sea water at Mithapur
Calcium carbonate ..	0.016	0.0221
Calcium sulphate ..	0.421	0.4549
Sodium chloride ..	16.038	17.2666
Magnesium sulphate ..	0.510	1.6016
Potassium chloride ..	0.275	0.4569
Calcium chloride ..	nil	0.0427
Magnesium chloride ..	4.647	1.9432
Magnesium bromide ..	0.057	0.1836
Total Solids	21.964	21.9816

ANALYSES OF SALINE RESIDUES

	Kharaghoda	Kuda	Mithapur
Sodium chloride	70.84	73.02	78.55
Magnesium chloride	22.36	21.16	8.84
Potassium chloride	1.98	1.25	2.08
Calcium chloride .. ..	..	..	0.19
Magnesium sulphate	2.31	2.32	7.30
Calcium sulphate	2.12	1.91	2.11
Calcium carbonate	0.05	0.08	0.10
Magnesium bromide	0.34	0.26	0.83
	100.00	100.00	100.00

TOTAL PRODUCTION OF MAGNESIUM CHLORIDE
(long tons), 1916-47

	Kharaghoda	Mithapur	Kuda	TOTAL
1916-18 ..	4,226			4,226
1919-23 ..	5,503			5,503
1924-8 ..	9,137			9,137
1929-33 ..	25,248	1,083	2,171	28,502
1934-8 ..	28,785	3,545	3,653	35,983
1939-43 ..	30,320	4,015	3,285	37,620
1944-7 ..	11,619	4,566	523	16,708
TOTAL ..	114,838	13,209	9,632	137,679

STRONTIUM MINERALS

Strontium is one of the alkaline earth metals and a close relative of calcium and barium, but its natural compounds are much scarcer than those of either of these elements and commercially are confined to two minerals, strontianite, the carbonate, SrCO_3 , with 70.2 per cent of strontia, SrO , and celestite, the sulphate, SrSO_4 , with 56.4 per cent of strontia.

Strontianite is a soft, pale green, yellow, grey or white mineral, crystallizing in the orthorhombic system but usually found in granular or fibrous forms. It has been identified in specimens from the Kharari valley, on the road to Las Bela, Baluchistan, and it occurs in small quantities with the celestite of the Uttattur Stage of the Cretaceous rocks of Tiruchirapalli, of which it is probably a weathered product.

Celestite too is a pale-coloured, soft mineral belonging to the orthorhombic system, sometimes found in tabular crystals with a perfect cleavage, resembling those of barytes, the sulphate of barium, from which it is easily distinguished by its lower specific gravity and its crimson flame reaction. It occurs more commonly in fibrous, radiating, concretionary or granular forms.

The celestite deposits of the Tiruchirapalli district of Madras are important: discovered in 1893 by Dr H. Warth, they were forgotten until 1939, when N. Jayaraman and Dr K. R. Krishnaswami identified the mineral again in specimens sent to the Indian Institute of Science, in Bangalore, by a company engaged in gypsum mining in the same region. The occurrence was investigated by Dr M. S. Krishnan and N. K. N. Aiyengar of the Geological Survey of India in the first quarter of 1940, and they have shown how the Uttattur clays are traversed by sparsely distributed veins of celestite, in an area lying between latitudes $11^\circ 2'$ and $11^\circ 9'$ and longitudes $78^\circ 5'$ and $78^\circ 56'$, and bounded by the following villages: Periyakurukkai, Neykulam,

Nambakkurichchi, Uttattur, Teranippalaiyam, Karai, Sirukanbur, Kulakkalnattam, Ayinapuram and Nallur. The veins near the first two villages are poor but those further north are better. The celestite, in coarse fibres and columnar crystals, forms cross-fibred veins, with a central line of junction where the fibres from the walls meet, one to four inches in thickness. External surfaces and central lines alike exhibit a little gypsum, calcite, strontianite and clay. The mineral generally has a light buff tint due to iron staining, but freshly broken is white, pale yellow or pale blue in colour. It is also found in negligible quantities filling cracks and forming concentric shells around phosphatic nodules and even replacing reptilian bones.

The veins are particularly abundant east of Uttattur and between Karai and Kulakkalnattam, where the abundance of surface weathered material is impressive and rather deceptive, for preliminary, shallow pitting showed that the celestite content is but 2 to 5 per cent of the volume of the gypsum contained in the strata. At the same time, as Dr M. S. Krishnan points out, this amounts to between 44,000 and 110,000 tons to a depth of 10 feet, or to something of the order of $\frac{1}{2}$ to 1 million tons, if the veins continue unaltered to a depth of 100 feet.

Celestite has been found at a number of localities along the low scarps of the 'Gypsum Hills', over a total distance of 3 or 4 miles, three to four miles east and north-east of Daud Khel railway station, on either side of the line in the Mianwali district of the West Punjab, Pakistan. The mineral occurs as fibres or radiating crystals in a network of cross-fibred veins, the mineralized zone being about 40 feet thick, closely associated with the massive gypsum of post-Nummulitic age, and overlain by the Chinji (Siwalik) formation. At one locality, $2\frac{1}{2}$ miles north-west of Jaba, there is a vein about 100 feet long and 3 to 5 feet thick, which rises prominently to a height of 6 to 12 feet above the surrounding country. Other promising localities exist in the neighbourhood of Khairabad. Trenching and pitting of the large vein mentioned showed reserves of the order of 7,000 to 10,000 tons to a depth of 20 feet, samples of the ore containing 82.7 per cent of strontium sulphate with silica and lime as impurities.

F. Fedden, of the Geological Survey of India, noted the occurrence of celestite in the Kohistan region of southern Sind as long ago as 1879, but it has only attracted attention within the last few years. A bed of crystals and granular masses of celestite of varying size, locally termed *chiroli*, occurs in Nummulitic limestone, dipping almost vertically, at the foot of the Sur Range, 6 miles west of Thana Bulla Khan. The whole length of the bed is not less than 2 or 3 miles, but taking a length of 1,200 feet, near Nimewari, where it has a thickness of $2\frac{1}{2}$ feet, the Geological Survey of Pakistan estimates a reserve of 10,000 tons to a depth of 30 feet. The location is waterless, the nearest supply,

and that a scarce one, being 6 miles away at Thana Bulla Khan, which is 24 miles from Meting railway station. Some quarrying of celestite has been done at Nimewari, the mineral being carried on camels for 4 miles, before loading on to motor trucks.

In 1949, A. M. Khan of the Geological Survey of Pakistan examined a lenticular, vertical vein of pure white celestite, in a prominent range of foraminiferal limestone (perhaps of Laki, Eocene age), 4 miles west of Kalu Kuhar, and about 20 miles north of Jungshahi, in the Dadu district of Sind. Its length is 70 yards, its maximum width 10 feet and its exposed depth 120 feet. The visible quantity available is 10,000 tons.

Strontium itself is a soft, white metal, of low specific gravity (2.6), which can be prepared by the electrolysis of its fused chloride. In its properties it resembles calcium but it is more reactive chemically than that metal, though like its sister element barium, it has still to find useful applications requiring substantial quantities.

Powdered celestite is sometimes used as a substitute for barytes, not only in the muds used in oil-well drilling, as in West Pakistan, but also in the various paints and pigments, compositions and fillers, in which that mineral is normally employed. Small amounts are also consumed for purifying caustic soda. The ground carbonate, strontianite, is used to remove sulphur and phosphorus from molten steel; at the same time it acts as a flux in the open-hearth furnace, increases the fluidity of the slag and reinforces its basic character. Both minerals are used in the preparation of salts, a number of which are employed in pyrotechnics, medicine and the glass and ceramic industries. The intense red or brilliant crimson colour of fireworks is due to the strontium compounds which they contain and for which there are no effective substitutes. They are also employed extensively, particularly in the form of the nitrate, peroxide and oxalate, in the fillings of flares for ships and aircraft, Very lights, military rockets, tracer bullets and in all kinds of signals required to burn with a red light.

It is incorrect to state, as many textbooks do, that strontium hydrate, $\text{Sr}(\text{OH})_2$, is used in the refining of sugar. It was utilized in a process developed years ago in Germany and France for the desugarizing of beet molasses, but this is not refining. Strontium is not the only element which possesses the power of forming saccharates with sugar, for while two saccharates of strontium exist, there are also three of lime and one of barium, and compounds of all three of these closely related elements have been, or are, employed on a commercial scale. The strontium, or Scheibler, process was still in operation at Dessau, in Germany, in 1924, but several other installations were lying idle at that time. The process is not used in the United States, Canada or Great Britain. The Steffen process, which utilizes the formation of the

saccharate of lime in diluted solutions of molasses, was and is used extensively in Europe. In the case of the beet-sugar industry of the United States, the residual molasses from the lime process is collected and is further treated by a barium process, at the Johnstown factory in Colorado, and a further crop of white sugar (sucrose) obtained from it. According to published information, Italy is the only other country where the barium process is in use at present. As far as Great Britain is concerned, no sugar is being recovered from molasses, indeed the home production of beet molasses has to be very largely increased by the importation of cane molasses, in order to meet the demands for the production of baker's yeast and industrial alcohol, the latter being the purpose for which increasing amounts of their own molasses supplies are required in India and Pakistan. We have to acknowledge the kind assistance of the Director of Research of Tate & Lyle Ltd in the collection of this information, from which it will be seen that there is very little hope of a demand for Indian strontium salts from factories engaged in the manufacture of sugar.

No statistics of the Indian imports of strontium salts are available, though they probably amount to a substantial tonnage annually, mainly for use in fireworks, but as the manufacture of such salts from strontianite is comparatively easy, there is no reason why they should not be prepared locally in both India and Pakistan. In pre-war years the world's annual production of strontium minerals was about 7,000 tons, of which the United Kingdom supplied over 90 per cent, from the celestite occurrences in the Triassic rocks of Gloucestershire. During the war years, however, new sources of celestite were developed in both Mexico and Spain, and the exports from the former country to the United States in 1943 alone totalled 9,876 tons. In 1947, the United Kingdom produced 4,824 tons of strontium minerals and Mexico about 2,000 tons of celestite. There is as yet no recorded output of celestite from India. In the years 1948 and 1949, a total of 1,040 tons was raised in the province of Sind, West Pakistan, while a further 200 tons of 'barite' from the same province, in 1948, is believed to have been composed largely, if not entirely, of celestite. For fuller details of these interesting minerals, the reader is referred to Dr M. S. Krishnan's comprehensive bulletin regarding them; in it will be found fuller accounts of their uses than can be given here, as well as of their grading, marketing and prices. The reserves of these minerals in both India and Pakistan are vastly larger than the requirements of either country of strontium chemicals at present, or in the foreseeable future. Any large-scale development of the deposits in Madras, West Punjab or Sind therefore, appears to depend on the possibility of placing high-grade, powdered celestite in the export market at ruling competitive prices.

MINERAL WATERS

The Indian peoples have recognized the value of the hot and mineralized springs of their country for ages: their localities are often objects of pilgrimage or the sites of annual fairs, and, rightly or wrongly, most of them are regarded as efficacious in the treatment of dermatic complaints, goitre, arthritis and other diseases.

Thomas Oldham, the first Director of the Geological Survey of India, published an account of the thermal springs in 1882 and his list, admittedly far from complete, contains the names of 298 separate localities; to it T. D. La Touche added a further 43 locations in 1918, remarking that these do not include all the hot springs, but only those waters reported to possess some medicinal value or known to be charged with mineral matter in solution. In 1939, Dr P. K. Ghosh and his colleagues B. C. Gupta and P. K. Chatterjee commenced a systematic investigation of the whole subject, which unfortunately came to a premature end owing to more pressing war-time demands, after field work in Bihar, Bombay, parts of Uttar Pradesh, Madhya Pradesh, the Punjab and Bengal, involving 112 occurrences, had been completed.

Dr Ghosh's account of his researches, aided as they were by elaborate chemical analyses of the waters by the King Institute of Guindy, Madras, the Public Health Laboratories of Poona and the Institute of Hygiene in Calcutta, is the standard work on this subject from which the following brief notes are mainly taken. It is shown that there are four belts of country in which the majority of the mineral springs occur: the first, in Bihar, more or less parallel to the boundaries of the coalfields, and in the Rajgir and Monghyr areas; the second, along the western coast of India, in the Ratnagiri, Thana, Kolaba and Surat districts of Bombay; the third and fourth, in the Sind-Baluchistan and Himalayan regions respectively. Outside these four broad belts, there are other smaller areas where the disposition of the springs follows the general tectonic trend of the country, notably in the Mahanadi valley of Orissa, the Birbhum and Darjeeling districts of West Bengal, parts of Assam, Sikkim, and certain portions of southern India.

For exact details of locations, compositions, temperatures and flow, the writings of Dr P. K. Ghosh should be consulted. It can only be pointed out here that waters equal in quality to those of many of the well-known European and American spas have now been proved to be available in large quantities in India and Pakistan. They include the following varieties:—(1) Waters of remarkable purity, carrying a minimum of foreign matter in solution, of cold types such as those of Patalsur and Parasnath, in the Hazaribagh district of Bihar, or the Mossy Fall of Mussoorie, in the Dehra Dun district of Uttar Pradesh, comparable with the well-known Evian waters, or again of thermal types

typified by the Brahmakund and other springs of Rajgir. (2) Alkaline waters, both cold and thermal, exemplified in the first case by the Brindhkal well of Banaras which is of Apollinaris type, and in the second by the mixed Vichy-like waters of Gandhwani, Hazaribagh district, Bihar; Chhota Anthoni, Hoshangabad district, Madhya Pradesh and Sohna, Gurgaon district, East Punjab. (3) Sulphuretted waters, cold, as at Sahasradhara, in the Dehra Dun district again, or hot, as at Duari and Surajkund, in Hazaribagh. These correspond broadly to the European Bad Neundorf and Aix-les-Bains waters, respectively. (4) Hot saline waters of the Marienquelle and Leamington Spa types, occurring at Umhera, in Kolaba, Unhara, in Ratnagiri, and in the Vajreshwari springs of the Thana district, Bombay.

Many of these Indian waters, and those of Bihar in particular, are radio-emanative while some springs in Bombay are said to possess permanent radio-activity.

A few examples from regions not included in Dr Ghosh's survey include the hot, sulphurous springs of Sikkim, one of which, at Monai, issues close to the foot of the Kanchanjhau glacier; the hot, chalybeate springs of Garhwal; the iodine-bearing, saline waters of Jawalamukhi, in the Kangra valley, and the many more springs, both hot and cold, of Himachal Pradesh, Spiti and Kashmir. In Baluchistan, there are the intensely saline and sulphurous springs of Kan Berar, in Las Bela, and those of Khattan, in Sibi, both of which groups deposit sulphur, saline encrustations and, in the latter case, calcareous tufa. Others are known in Kachhi and the Bolan Pass.

Hot springs have a wide distribution in Burma, from the Palau subdivision of Mergui in the south, through Tenasserim, Karenni and the Shan States and thence across the frontier into Yunnan. The hottest springs, with temperatures up to 198° F., form a group issuing from granite near Pai, in the extreme south of Tavoy district. Further north, near Myittha, another group occurs, in this case of a sulphurous character. Still more are found at Laukchan and Yebusan. The hot springs of Attaran, in Amherst district, form large ponds of hot, carbonated and ferruginous water, while others are known on Belugyun Island, near Moulmein. The hot springs of Kehsi Mansam, with temperatures of about 104° F., are the best known in the Southern Shan States. In the Northern States, 4 miles north of Lashio, there is a very copious discharge of water, not far from boiling point, charged with sulphate of lime and magnesia.

Well advertised mineral waters have an economic value as the numerous kinds from Europe and Japan offered for sale in India demonstrate. The water of a spring at Sipri, in Gwalior, has been bottled and marketed by a Bombay firm, while those of Sitakund, near Monghyr, were utilized by a soda water manufacturer in Calcutta, but beyond these no commercial developments

appear to have been attempted. No statistics are available of the value of foreign waters imported into India, 'nor', adds Dr Ghosh, 'of the amount of money spent by Indians on spa-treatment abroad'. The ownership of the medicinal springs is vested either in private hands or in religious bodies, but he adds, 'times are changing fast and it may not be long before such owners will wake up to the call of a progressive age'. When that day arrives it will remain for the medical profession and the capitalist between them to turn these bountiful and beneficent gifts of nature into the sites of modern spa sanatoria.

LITHOGRAPHIC STONES

The art of printing from drawings made on stone is said to have been introduced into India in 1822 by T. N. Rind, who was afterwards placed in charge of the Government Lithographic Press. As the process proved applicable to the reproduction of the various Indian scripts, where types were not available, it was not long before it was adopted all over the country, and the number of presses using it, mostly in Indian hands, was, in the course of a few years, very considerable. The great cost of suitable stones imported from Europe early led to trials of stones of indigenous origin, which it was hoped would supplant those bought from abroad. Writing in 1881 on the general character of lithographic stones, Valentine Ball made the following observations: 'Limestones suitable for lithographic purposes are not of wide distribution; the combination of qualities requisite are not often found united. The best stones are compact and uniform in texture, and are free from veins, flaws and spots; they are generally of light colours, for although stones of dark colour can be used for certain purposes, for others it is necessary that the lithographer should have a light ground to work upon.' Ball quotes a number of localities where more or less suitable limestones might be obtained, and many of them are of Vindhyan age, though the Jurassic and younger rocks of Jaisalmer, Kutch and the Punjab are also included. A fuller list can be found in T. D. La Touche's *Bibliography*, though he adds: 'No thoroughly efficient substitute for the lithographic stone imported from Germany has yet been found in India, but stone that answers the purpose fairly well has been met with at several places.'

During the first world war (1914-18), when the supply of German stones entirely ceased, experiments with various Indian stones were made, and although some of them proved suitable for the rougher kinds of work, on the whole their performances did not approach those of the finer qualities of the German and Austrian stones, and, with the end of hostilities, it was not long before these again regained their former position in the Indian market. Today, the spread of newer methods of printing has

reduced the demand, especially in the Calcutta market, to very small proportions. In some places, however, as, for example, around Sivakasi, in the Ramanathapuram (Ramnad) district of Madras, there are still many flat-bed litho-printing machines in use, but the life of a good stone is a lengthy one, and such new ones as are required are obtained from Germany or Austria.

The most promising material available in India is obtainable in certain bands of the Narji Stage of the Kurnool Series, which has a wide distribution in the Kurnool, Guntur and Krishna districts of Andhra; the best varieties coming from Dachapilli, in Guntur; from Kondapilli and Jaggayapetta in Krishna, and from various places in the Tungabhadra valley of Kurnool. In Pakistan, some varieties of the limestones of the Khirthar Group of Sind have been recommended as suitable lithographic stones.

ZEOLITES

The zeolites form a large family of hydrated silicates of calcium and aluminium, sometimes with sodium, potassium and barium. In composition, association and mode of occurrence they are closely related, and when heated before the blowpipe they swell, froth and appear to boil, qualities which have given the family its name, from two Greek words meaning 'to boil' and 'stone'. They are found, often in beautiful crystals, lining the cavities of basic igneous rocks, and are unusually abundant in some of the flows of the Deccan Traps, where they occur not only in hollows and cracks, but as solid amygdules, especially in the more decomposed beds of lava, and, being more resistant to weathering than the enclosing rock, they remain strewn on the surface as it disintegrates. They are closely associated with, and sometimes coated by layers of 'green earth', or celadonite, a mineral which is abundant in the amygdaloidal flows of the Deccan Trap, often filling the smaller cavities completely. It is supposed to be a silicate of iron, magnesium and potassium, though no full analyses of the Indian mineral are available.

Stilbite, a hydrated silicate of sodium, calcium and aluminium $(\text{Na}_2\text{Ca})(\text{Al}_2\text{Si}_8)\text{O}_{16}\cdot 6\text{H}_2\text{O}$, is perhaps the commonest Indian zeolite, while next in abundance are apophyllite, a hydrated calcium potassium fluosilicate, $\text{KFCa}_2\text{Si}_8\text{O}_{20}\cdot 8\text{H}_2\text{O}$, which is not a true zeolite but is usually included in the family; heulandite, a hydrous silicate of calcium and aluminium, $\text{Ca}_2(\text{Al}_4\text{Si}_4)\text{O}_{38}\cdot 12\text{H}_2\text{O}$; scolecite, $\text{Ca}(\text{Al}_2\text{Si}_3\text{O}_{10})\cdot 3\text{H}_2\text{O}$; and laumontite, $(\text{Ca},\text{Na})(\text{Al}_2\text{Si}_4)\text{O}_{12}\cdot 4\text{H}_2\text{O}$; while thomsonite, $\text{NaCa}_2(\text{Al}_5\text{Si}_5\text{O}_{20})\cdot 6\text{H}_2\text{O}$, chabazite, $(\text{Ca},\text{Na})(\text{Al}_2\text{Si}_4)\text{O}_{12}\cdot 6\text{H}_2\text{O}$, and a number of others also occur. Beyond furnishing magnificent specimens to the mineral galleries of museums in many parts of the world, Indian zeolites have had no other uses. Readers interested in exact details of the various occurrences are referred to the lists, too

lengthy to reproduce here, given by T. D. La Touche in his indexes to the Records and Memoirs of the Geological Survey of India. To them may be added a new find near Barpalli, in Daspalla, Orissa, where stilbite is present as transparent plates and radiating fibrous masses in pink, biotite gneiss.

In 1850, the English chemist, Thomas Way, discovered the phenomenon of base-exchange and in 1858 Eichhorn showed that the natural zeolites possess this property. Under suitable conditions the metallic constituent of the alumino-silicate portion of the zeolite can be replaced by other metals; moreover, the process is reversible. Thus when 'hard' water, which may contain the bicarbonates, sulphates or chlorides of calcium and magnesium in solution, is passed through a bed of zeolites, crushed and screened to suitable sizes, the calcium and magnesium ions which it is carrying are exchanged for the sodium ions of the zeolite, the water becomes 'soft' and no longer needs inordinate quantities of soap to form a lather, or forms scale when used as boiler feed water. This softening action continues until the base-exchange material, in this case the zeolite, contains no more sodium ions to exchange for calcium and magnesium. It must then be regenerated with a pre-determined quantity of common salt brine, washed to remove all hardness salts, when it is again ready to soften the next batch of 'hard' water. This cycle of alternate softening and regeneration can be repeated almost indefinitely.

Natural zeolites were first used in the beet-sugar industry about 1896, to replace the potassium compounds of sugar juices by calcium and so increase the yield of sugar crystals. It was in the early years of the present century that the base-exchange silicates were first developed for water-softening, for both domestic and industrial uses, by the German chemist, R. Gans. It was soon found, however, that other minerals, particularly glauconitic greensand, fuller's earths and other clays, possess this property of base-exchange and that natural zeolites could be closely imitated by artificial compounds, such as the porous gels made by fusing mixtures of quartz sand, kaolin and soda ash, or by mixing solutions of sodium aluminate and sodium silicate. Later still came the discovery that sulphonated coal and certain synthetic resins are even more active agents for the same purpose. Thus the term 'zeolite' has been expanded far beyond its true and original meaning, and in commercial usage may now include all or any of the following three groups of materials used for water softening by exchange:

- (1) Natural zeolites, purified mechanically and then treated chemically to enhance their properties.
- (2) Synthetic zeolites, formed by fusion or by chemical combination in solution.
- (3) Carbonaceous materials, produced by activating coal, peat and lignite with sulphuric acid and certain synthetic resins.

These newer materials can be made acid-resistant so that the exchange of hydrogen ions for sodium, magnesium and calcium becomes possible, thus possessing considerable advantages over the older ones as their regeneration is equally easy. By suitable combinations of base and cation exchange, salts can now be completely removed from solution and practically pure water obtained. Such processes are in operation on a large scale in chemical works, distilleries, high-pressure boiler houses and so on.

The only natural mineral in common use today for water softening is glauconite, a complex, hydrous silicate of iron and potassium, also containing some aluminium, magnesium and calcium. Its formula possibly is $K_2(Mg,Fe)_2Al_6(Si_4O_{10})_3(OH)_{12}$. It occurs principally as a constituent of the Cretaceous greensands, in small, angular or sub-rounded grains, 0.25 to 1 mm. in diameter and of yellowish to blackish-green colours. It is also found in sub-littoral, marine deposits in actual formation at the present time.

As the calcium ion concentration of natural hard waters is rarely sufficient to effect direct replacement of the potassium ions in glauconite, the mineral is usually activated by treatment with a solution of sodium chloride, to substitute its replaceable potassium ions by sodium ions. These readily make way for the calcium ions in any hard water passed over the activated mineral, which when exhausted can be regenerated once more by brine.

Activated glauconites sold under various trade names are still used for large-scale softening of water for industrial processes, but the synthetic materials of the third group are steadily gaining ground. Greensand production in New Jersey, U.S.A., is now limited to from 4,000 to 8,000 tons per annum, whereas 15,000 tons of synthetic 'zeolite' are made annually. Glauconite is also recovered from the greensands of Gingin, in Western Australia, of which it forms about 20 per cent of the bulk, by electrostatic separation, and while there is still a small demand for the mineral as refilling for existing plants, it is judged to be only a question of time before it is ousted completely. The reason for this is apparent from the figures which follow.

Base-exchange materials are assessed by their exchange value, that is to say by the weight of the equivalent quantity of calcium carbonate, in grains, removed from a hard water by 1 cubic foot of material, when under standard conditions hard water passed through it just ceases to be of zero hardness. Greensand has an exchange capacity of some 3,000 to 4,000 grains of calcium carbonate equivalent per cubic foot, and by activating the mineral this can be increased to 5,000 or 5,500 grains. The corresponding figures for the carbonaceous materials are given as from 8,000 to 10,000 grains; for the synthetic sodium aluminosilicates as about 15,000 grains, and for the synthetic resins as from 10,000 to 25,000 grains per cubic foot.

Glauconite has been found at numerous localities in India, Pakistan and Burma, in rocks ranging from the Lower Vindhyan to the Miocene in age. Of the more important occurrences are the greensands of the Lameta (Cretaceous) Group of the Jabalpur district, Madhya Pradesh; the glauconite-bearing, calcareous sandstones of Upper Cretaceous age, described by Wadia from the Margala slopes which border the northern margin of the Potwar, in the Punjab; and the strong bands of dark green sandstone, again of Cretaceous age, to be seen near Maosmai and Laitsoke, in the Khasi Hills of Assam.

Closely related to glauconite in composition is the mineral celadonite, usually found in association with basalt and particularly in the Deccan Trap. It is the principal constituent of the green earth which, as already mentioned, sometimes coats their zeolites and fills their small cavities; in addition, however, it occasionally forms inter-Trappean layers and irregular seams and pockets in the flows themselves. One of these vesicular fillings from Bhusawal, in the East Khandesh district of Bombay, analysed by P. C. Roy, contained 7.65 per cent of potash, but the base-exchange values of the Indian green earths have still to be determined. Otherwise, the only economic possibilities for the mineral are as an adsorbent or fixing base for aniline colours in the paint industry.

Greensands have been utilized as effective potash fertilizers in some countries, in situations close to their sources of supply, but full analyses of the Indian minerals are needed before any opinion can be given as to their local value in this respect.

Some dehydrated zeolites, using the word in its strict mineralogical sense, act not only as sorbents but also as molecular sieves. Chabazite, for example, has been used to separate various gaseous and liquid hydrocarbon mixtures, and the differentiation of many complex organic compounds can be effected by its use.



PART IV

PRECIOUS AND SEMI-PRECIOUS STONES



CHAPTER XV

PRECIOUS STONES

IN both ancient and medieval times, India, including Ceylon, was the world's chief source of precious stones, a fact which the Roman author Pliny (A.D. 23-79) was well aware of when he wrote—'of lands, India produces more gemstones than any other'.¹

In the *Mahabharata*, one of the great Sanskrit epic poems, there are many references to gems, and there are also other texts of high antiquity such as the *Sukraniti* and the *Susruta* in which the diamond, emerald, chrysoberyl and rock crystal are mentioned. Scholars are not agreed on the exact dates of these ancient writings and diverse views prevail regarding them. The consensus of opinion today tends towards the assumption that a major portion of the *Mahabharata* text was fixed in its present form between the 1st and 3rd centuries A.D., but it is known to be the product of successive ages and at what period in time its references to precious stones were incorporated is not known. Diamonds, gemstones and the ores of a number of metals are referred to in the *Arthasastra* of Kautilya, dated by some authorities between 321 and 296 B.C., and by others as written sometime before A.D. 300.

Apart from such scattered literary allusions, however, in the course of time a whole corpus of information regarding gemstones was brought together for the benefit of those engaged in the gem business, or interested in the study of the stones themselves. This is known as *Ratnapariksa*. According to the French savant, Louis Finot, the earliest reference to it is in the *Kamasutra* of Vatsyayana, who is dated roughly about the 2nd or 3rd century A.D., but the most complete accounts are the *Ratnapariksa* of Buddhahatta, about whom nothing is known, and the unfinished (?) *Brihatsamhita* of Varahamihira (A.D. 505-87). There is some reason to suppose that both these writers were redacting still earlier texts. After the *Brihatsamhita* the properties of gemstones and the methods of their identification are briefly described in the *Agnipurana* and more elaborately in the *Garudapurana*; both these texts were in their present form in the 9th or 10th century A.D., according to Joges-chandra Ray. Another important treatise on the same subject is the *Agastiyamatam* (Agastya's *Ratnapariksa*) which P. K. Gode, of the Bhandarkar Oriental Research Institute of Poona, kindly informs us is earlier than A.D. 1000. Finally, the *Yuktikalpataru*

¹ Pliny, xxii, 76.

of Bhojaraja, considered by Jogeschandra Ray to have been compiled in the 11th century A.D., contains a chapter on gems based on information derived from earlier works.

The ancient works enumerated include catalogues of both gems and semi-precious stones, dividing them into species and varieties and enumerating such physical properties as density, colour and brilliance, as well as their common defects. The regions from which they were derived are given, in addition to the distinctions which specimens from varying localities possessed. Notes are added on their imitations and the means of their detection, together with tariffs of their prices and accounts of the magical properties, both beneficial and baneful, with which each was supposed to be endowed.

Buddhabhatta's work enumerates nine precious stones divided into two classes—*Maharatnani* (lit. 'great gems') including the diamond, pearl, ruby, sapphire and emerald, and *Uparatnani* (lit. 'secondary gems') with zircon, topaz, cat's eye and red coral. To these are added five more—rock crystal, chrysoberyl, *bhisma* (?), garnet and carnelian. Varahamihira's list contains twenty-two names, of which he only described four stones, the diamond, pearl, ruby and emerald. Of the twenty-two enumerated, some are merely varieties of ruby, sapphire and rock crystal (possibly amethyst). To this list may be added the turquoise, lapis lazuli and heliotrope of the later commentators.

In the following account we have adopted a threefold, arbitrary division into Precious Stones, Uncommon Gem Stones and Semi-Precious and Decorative Stones.

DIAMOND

Until the discovery of diamonds in Brazil about 1725, India alone supplied the world with the gems and had probably done so for the preceding 2,300 or 2,400 years. There are references to the Indian sources in the works of both Greek and Roman writers, but, naturally, it is in early Sanskrit literature that the producing regions are first broadly indicated. It is not surprising then that most of the great historical diamonds such as the Koh-i-Nur, Pitt (or Regent), Orloff, Florentine, Dresden Green and many others are of Indian origin, for at one time the industry was of considerable extent and importance though today the production of diamonds is relatively insignificant.

Though the French jeweller, Jean-Baptiste Tavernier, gave the earliest detailed account of the Indian diamond fields, as a result of his travels in 1665-9, they had already been alluded to by earlier European visitors to India from the thirteenth century onwards. They are grouped in three extensive though widely separated tracts, the most southerly of which, often wrongly referred to as 'Golconda', embraces parts of the Anantapur, Cuddapah,

Guntur, Krishna and Kurnool districts of Andhra. The second tract occupies a region between the Mahanadi and Godavari valleys, and the third, comprising the diamond fields of Vindhya Pradesh, lies along the northern scarps of the Vindhya Range in Bundelkhand. It is in this tract and mainly around Panna that diamond mining still persists.

Many accounts of the diamond mines of southern India have been published and long lists of the localities of the mines are available. All that can be attempted here is to indicate broadly the more important areas, and to refer the reader in search of further information to the comprehensive summary of the whole subject published in 1951 by Dr M. S. Krishnan in his *Mineral Resources of Madras*.

Commencing with Anantapur in the west, the best known locality is Wajra Karur, about 8 miles south of Guntakal Junction on the Southern Railway, where good stones are still found in the fields from time to time after rainy weather. A tuff-agglomerate 'neck' with epidote rock here was at one time thought to be the source of the gems, but various attempts to recover them from it have ended in failure. In 1884-5 deep prospecting on behalf of a Madras syndicate did not unearth a single stone, while more recent exploration by the New Wajra Karur Diamond Mining Co. Ltd, the affairs of which were wound up in 1941, only yielded two stones weighing 1.80 carats. Some fourteen separate localities, lying in a roughly rhomb-shaped tract, bounded on the west by Lattavaram and Guntakal and on the east by Gooty and Dhone (including small parts of the adjoining Bellary and Kurnool districts), possessed diamond workings in the sixteenth and seventeenth centuries. Valuable stones are still found around one of these places, Konganapalli, in the Gooty taluk, particulars of which sometimes reach the authorities. One such stone, picked up in a field by a cultivator in June 1939, was sold by him in Bombay for Rs 16,000. He preferred to abscond rather than pay the royalty of Rs 4,086 due to Government, surrendered when his lands were brought to sale, and was lodged in Bellary jail in December, 1941, to be released again after promising to pay the royalty in annual instalments over a period of nine years. There can be no doubt about the authenticity of this particular diamond find.

According to P. Venkayya, a Gooty prospector quoted by Dr Krishnan, epidote-bearing pegmatites intrusive into hornblende and epidotic granite-gneisses of the region used to be worked for their diamond content, and at several places within the area mentioned above there is abundant evidence in the pegmatite debris crushed by the old miners around the small platforms on which it was washed.

In the Cuddapah district, to the south-east of Anantapur, a diamond-bearing gravel bed was exploited at numerous places on both banks of the Penner river, near Chhinur, a village close to

Cuddapah town. A general account of them was given by Gribble in the Cuddapah Manual (1875), and fuller descriptions by Captain Newbold who visited the area while operations were still in progress in 1840.

In the south Indian tract generally, most of the workings were in alluvial, gem-bearing gravels of sub-Recent age, but in the Kurnool district which lies to the north of Anantapur the stones were won *in situ* at Banganapalle and elsewhere. Hereabouts, underlying 20 or 30 feet of quartzite, easily penetrated by shallow shafts, are beds of coarse conglomerate and breccia with seams of shaly and clayey stuff, six to eight inches thick, full of small pebbles and fragments of shale, quartzite, chert and grains of sand. In these seams the diamonds occurred, mainly as small, peppercorn-sized modifications of the octahedron, pale blue, green or yellow in colour and unworn. This particular conglomerate lies at the base of the lowest sandstone horizon, the Banganapalle Stage of the Kurnool System. It is exposed over a large area west of the town of the same name, and extends for some 15 or 16 miles, west by south, to Madavaram and Munimadugu. Again, east of Basavapuram, there is another spread of about two square miles in extent, at the base of the Nallamalais, which has many ancient workings both in the conglomerate itself and in the local alluvium. Near Ramallakota (Raulconda), 18 miles south by west of Kurnool itself, there were both rock and surface workings from which small stones of excellent quality are said to have been obtained. An account of the diamond mines in this district has been given by Gopalakristnamah Chetty in the Kurnool Manual and there are many references to them in other writings, particularly those of W. King of the Geological Survey of India. During the years 1910 to 1912, A. Ghose prospected a bed of diamond-bearing conglomerate at Virapalle, in the Dhone taluk; varying between 3 inches and 2 feet in thickness, it yielded from $\frac{1}{2}$ to $\frac{1}{4}$ carat from each load of 16 cubic feet, most of the stones being perfect crystals of fine quality and free from flaws.

As the more detailed geological survey of the country progresses, the list of localities where diamond mining was practised in olden times grows longer. Thus Coulson found previously unrecorded workings in 1932, near the villages of Balapuram and Repalle, in the Dhone taluk, while more ancient workings were discovered in 1948 by Venkatesh in the Cuddapah basin at Kalava, Chautukur, Puduru and Marugutti. Coulson suggested that the diamonds in the Banganapalli Beds have been derived by weathering from certain trap sills, intrusive into the Papaganni and Cheyair Series of the Cuddapah System, sills which are thought to be of the same age as the decomposed tuff-agglomerate at Wajra Karur, in Anantapur.

To the north-east of Kurnool lie the districts of Guntur and Krishna, both of which contain many old workings. Kollur, the

reputed home of the famous Great Mogul diamond ($787\frac{1}{2}$ carats), presented to Shah Jehan by Mir Jamla in 1656, lies on the right bank of the Krishna in the Guntur district. According to Tavernier, the workings were entirely of an alluvial character, seldom more than 14 feet deep, and not extending below the level of the ground-water were more or less exhausted by 1677. There are other old workings at Madagula, Mallavaram and Sarangapalli.

In the Krishna district, all the old mines are located on the left bank of the river and one important group was centred around Partial, some 17 miles as the crow flies north-west of Vijayawada (Bezwada). Another group lies about Ustapalli and Kodavatakalu, further upstream and beyond the junction of the Munyair and the Krishna. In all these cases the bearing horizon is a detrital, sub-Recent bed resting on metamorphic rocks. The Hyderabad (Deccan) Company opened up the old workings at Partial and extracted 3,444 stones of a total weight of 2,085 carats, but most were of poor quality and the enterprise was abandoned in 1894. In another part of the same district there are old workings on lateritic sandstones, overlying the sandstones of the Golapilly area, some 24 miles north-east of Vijayawada.

The Krishna river forms the boundary between the Guntur district and Hyderabad, and in the south of that State it cuts through the Amrabad plateau composed of rocks of the Cuddapah System, in a great gorge about one hundred miles long. Interbedded in these rocks are several basic sills with ancient diamond workings in the river gravels just below their outcrops. The old workings of Kollur and Partial are all situated downstream below the mouth of the gorge, and a suggestion by Dr A. M. Heron that the sills are the original home of the gems is much the same as that advanced by Dr Coulson. Diamonds are also reported to have been found occasionally in the bed of the Godavari river, near Bhadrachalam in the East Godavari district.

Although there were many active workings during the earlier part of the nineteenth century, diamond mining gradually came to an end in southern India, the last recorded returns of a trivial quantity being in 1913. Whatever causes may have been responsible for this, exhaustion of the deposits as a whole was not one of them, for, as V. Ball pointed out, the diamond-bearing strata have a wider extension than the earlier miners realized. Careful prospecting of some of the untouched areas, using proper equipment under expert geological direction, is essential before any plans for mining development can be considered. Previous attempts have been on wrong locations or on too petty a scale to offer any trustworthy guidance to the future. As regards alluvial mining of the diamond-bearing gravels, the experiment of the Hyderabad (Deccan) Company, the most ambitious one of its kind, took place on an ill-chosen, worked-over area at Partial.

Captain L. Munn, Mining Engineer to the Government of Hyderabad, regarded it as a mistake which merely proved the futility of cleaning up old workings. Yet there still remain large expanses where such gravels lie untouched, protected by the water under which the ancient miners were unable to penetrate far. Munn advocated suction dredging to work over selected portions of the 30 square miles or so of Krishna gravels around Partial, particularly of the deeper waterlogged layers, concluding that 'with a modern dredging plant, this area presents a very promising speculation'.

In the second tract diamonds have been found in the Mahanadi alluvium in the Sambalpur district of Orissa, in lateritic grits at Wairagarh, Chanda district, Madhya Pradesh, and in the sands of the Koel river, a tributary of the Son, in the Palamau district of Bihar. The best known locality is the Hirakund, a small island, about three miles long and half a mile wide, between two channels of the Mahanadi, some 5 miles north-west of Sambalpur town. The earliest account of the workings here was given by Motte, who had the misfortune to be deputed there by Lord Clive in 1766. V. Ball visited the area in 1877 and published an account of the methods adopted in searching for the gems. No stones have come from this tract for very many years and the source of the diamonds that were obtained in it is unknown. Ball believed that they were derived from extensions of the Kurnool or the Lower Vindhyan rocks into the region. On the other hand T. L. Walker, who found minute diamonds in sands from streams near Bondesor, in Kalahandi, states that they must have been derived from Khondalites. The streams in question are tributaries of the Tel, itself an affluent of the Mahanadi.

In the third tract, the diamond fields of Vindhya Pradesh are scattered over an area some 60 miles long by 10 miles wide, across a number of the former small States of the Bundelkhand Agency, the most extensive workings being in Panna, where diamond mining on a small scale still persists and where large-scale exploration is now in progress. The primitive methods employed in the search for the gems have been described by many writers from the time of Buchanan-Hamilton, in 1819, onwards, but the fullest account is that of E. Vredenburg of the Geological Survey of India (1906).

Vredenburg proved that the principal diamond-bearing layer is a thin band of indurated, sandy conglomerate, locally known as *mudda*, lying at the base of the Jhiri Shales, themselves the highest stage of the Lower Rewah Series in the Upper Vindhyan, and directly upon the Kaimur Sandstones. From this conglomerate the pebbles sometimes extend upwards, to make discontinuous bands with a shaly matrix which also contain diamonds and are known to the miners as *kakra*. The main conglomerate itself is not always continuous and seldom thicker than two feet. The

pebbles associated with the diamonds are chiefly vein quartz from the Bundelkhand granite, jasper from the Bijawar Series and green quartzite (*kansiya*) from the Lower Vindhya. In some parts of the region it is suspected that there is a second diamondiferous conglomerate, lying at the top of the Upper Rewah sandstones, which themselves come above the Jhiri Shales.

At the time of Vredenburg's survey there were thirty-six 'principal localities that have yielded diamonds', in six separate States of Bundelkhand, distributed as follows: Panna, 24; Charkari, 4; Chobpur, 3; Patarkhechar, 2; Kothi, 2; and Bijawar, 1. Of the total 36, 28 were connected with the older and 8 with the newer conglomerate. As regards methods employed, 4 were places where the conglomerate was extracted *in situ*; 16 were shallow surface workings; 15 were alluvial workings and at the remaining one shallow mining and alluvial operations were combined. Wide shafts were sunk, sometimes to a depth of 50 feet, down to the conglomerate which was then heated by fires to cause cracking and ease the work of extraction. The shallow workings were located on exposures of the conglomerate laid bare by weathering agencies, and on the detrital spreads derived from their denudation; the alluvial workings were in streams draining the outcrops, and the gem-bearing, water-sorted gravels were often buried under considerable thicknesses of soil, so that pits, often up to 30 feet deep, were necessary to reach them. After extraction, the conglomerate was broken up, pounded in shallow pits, washed and finally spread out on a cleared space before being repeatedly hand-picked and searched. These methods, identical with those described by Franklin in 1829 and by Jacquemont in 1830, are presumably the same as those followed for centuries earlier: considering their haphazard character, the limitation of operations to a short period in the dry season, the labour expended in sinking new pits every year, the want of care in disposal of waste, resulting in the frequent rehandling of accumulated debris, and, in general, the lack of any systematic planning, the wonder is not that the industry is so small but that it has survived at all.

Panna diamonds belong exclusively to a few modifications of the hexakisoctahedron, the most complex form of the cubic system, bounded by 48 similar faces, and so called from its resemblance to an octahedron having a low, six-sided pyramid raised upon each face. The average weight of 240 stones examined by Vredenburg was 0.63 *ratti*, or 0.59 carat, the Panna *ratti* weighing 0.9418 carat. Fifty-nine of these stones weighed one *ratti* and over; 181 weighed less than a *ratti*. The majority were remarkably perfect crystals, either brilliant white or blue-white in colour, of beautiful water and lustre and very seldom clouded or flawed; their commonest defect being 'spots'—black, opaque inclusions of jagged outline. The outer surface of crystals with a colourless interior is sometimes of a very pale straw-yellow, but being only

a thin film, it disappears on cutting. The same is true of the very beautiful, pale sea-green stones of exquisite delicacy in their natural state, which are known as *banspat* (bamboo leaves), but greenish crystals of a far less pleasant hue are fairly numerous and are of inferior value as the colour spreads throughout the stone. Some 17 per cent of the stones examined were of various shades of brown, sometimes a very deep brown, though opaque black diamonds are said to have never been found. The brown stones are known as *matta* and are of little value. The stones were sold by auction at Panna, at the beginning of each month. In the case of stones under 6 *rattis* in weight, the owner obtained three-quarters of the selling price and the State one quarter. After the highest bid, the original owner had the option of buying back the stone at that figure. Stones of 6 *rattis* or over became the property of the State, the finder in that case receiving one quarter of its value.

ANNUAL AVERAGE PRODUCTION OF DIAMONDS
IN VINDHYA PRADESH, 1904-51

PERIOD	CARATS	VALUE Rs	PERIOD	CARATS	VALUE Rs
1904-8 ..	306.71	41,985	1929-33 ..	1,436.8	74,040
1909-13* ..	84.30	13,080	1934-8 ..	1,649	72,868
1914-18 ..	42.57	18,240	1939-43 ..	2,118.6	1,88,212
1919-23 ..	161.94	92,124	1944-8 ..	1,607	2,33,078
1924-8 ..	223.78	36,237	1949-51 ..	2,025	4,09,071

* Includes 38.36 carats from parts of Madras now in Andhra.

Comparing the conditions in Bundelkhand with those of southern India, it is more than a coincidence that in both regions the diamonds are found in conglomerates of Vindhyan age, close to a crystalline granitic or gneissic area traversed by innumerable basic dykes of Bijawar age. For reasons too lengthy to be detailed here, Vredenburg suggested that the diamonds are not older than the Bijawars, a supposition which, he added, 'points to the basic dykes of Bijawar age as their possible nidus'. In 1930, however, twenty-four years after Vredenburg's pronouncement, K. P. Sinor published a description of a volcanic neck or pipe filled in with a diamond-bearing agglomerate-tuff at Majhgawan, 12 miles south-west of Panna town. In 1949 fuller details of the occurrence were given by V. S. Dubey and Sukumar Merh, and again by Merh alone in 1952. In the meantime T. C. Bagchi had described the diamondiferous rock as a yellowish or yellowish green, volcanic agglomerate with pseudomorphs of serpentine after olivine, pebbles of red jasper and xenoliths of black shale. The latest account by S. M. Mathur of the Geological Survey of India appeared in 1953. He gives the total surface area of the neck as approximately 112,500

square yards, accepts its age as post-Kaimur, though the possibility of further volcanic activity of the same type during and just after Rewa times cannot be excluded, and adds the suggestion, already advanced by Mehr, that other pipes of similar character may lie hidden under younger rocks or alluvium.¹

The principal producers of diamonds in the tract at the present time are the Panna Diamond Mining Syndicate, the Mahalaxmi Diamond Mining Works and the Charkhari Mining Works, which operates a large open-cast near Ramkheria, from which diamonds to the value of Rs 3½ lakhs approximately were won in 1952. The Panna Diamond Mining Syndicate commenced operations in 1936, but owing to the war and other causes little beyond prospecting was possible before 1949. A mechanical washing plant has now been installed at Majhgawan, to treat material mined from the agglomerate already mentioned. It consists of two 8-foot washing pans of the South African type, from which the concentrate goes to vibrating screens for classification before being passed over standard grease-tables. The Syndicate has also leased areas around Shahidan and along the course of the Baghen river, the gravels of which it is proposed to work on a large scale by mechanical excavators. At Shahidan a main shaft, 62 feet in depth, has been sunk and the diamond-bearing conglomerate found in various cross cuts and drives, its yield being very variable but averaging, it is said, about 0.25 carat per ton. Certain shallow and uneven deposits in river banks and streambeds have been subleased to local miners. Between 1936 and 1950, the Syndicate has recovered 23,653 stones of a total weight of 17,768 *rattis*, or 16,152 carats, reckoning the Panna *ratti* as the equivalent of ten-elevenths of one carat. These stones were sold for Rs 22,35,115. The largest gem found in recent years weighs 30 *rattis*. Unless large-scale systematic operations of the kind described continue, the diamond fields of Vindhya Pradesh cannot be expected to do more than provide a part-time occupation for some of the local inhabitants, in much the same way as they have done in the past. Three Russian technicians arrived in New Delhi in September 1954 as the advance party of a construction team which is to instal machinery for the Panna Mining Syndicate.

Leaving out of consideration surface and alluvial workings and confining attention to future rock mining possibilities only, if the occurrence at Majhgawan proves to be a true pipe of a kimberlite character it is likely to descend to great depths. Various estimates of its diamond yield have been given, tests by Waters and Royden

¹ In 1953 J. A. Straczek stated that the Majhgawan pipe is intrusive into the rocks containing the diamond-bearing conglomerate. If so, the pipe is of post-Rewa age and cannot be the original source of the gems. According to Straczek 60 per cent of the diamonds from the pipe are of industrial quality while 80 per cent from the conglomerates and gravel are of the gem grades. (*U.S. Bur. Mines Miner. Trade Notes*, 36 (5), 1953.)

Harrison in 1950, for example, resulted in the recovery of nine diamonds weighing 3.32 carats, from 305 cubic feet of the agglomerate-tuff, but the diamond content of such pipes may change greatly from place to place, so that even large bulk samples from one or two points may not be reliable guides to the content of the pipe as a whole. This, however, should be decided by the large-scale exploratory operations now in progress.

The main diamond-bearing conglomerate, by reason of its constancy and the regularity of its disposition, should present no unusual problems to the mining engineer. The earlier mines are situated at short distances apart all along its outcrop, and they were continued into the bearing-horizon until water or other material trouble prevented any further advance. The locations of new shafts should be left entirely to geologists well versed in the local stratigraphy, for as Vredenburg showed, a shaft at the foot of the Rewa scarp will have to be about 250 feet deep to reach the diamond-bearing rock. On the Upper Rewa dip slope it would have to traverse the whole thickness of the Rewa Sandstone, which would add enormously to its cost. But at any point about half-way between the Upper Rewa scarp and the northern boundary of the Lower Rewa shales (or limestones) the conglomerate may be expected at about 100 feet from the surface. The shaft would then constitute the deepest portion of the mine, and work would proceed by galleries driven up the dip slope, the drainage being pumped from the shaft. Vredenburg, after a detailed study of the problem, which has altered little since his time, concluded as follows:

'The area that can be profitably worked is practically coincident with the outcrop of the Rewa Shales. The conglomerate is known to occur as far as Bambia on the eastern side and Kishengarh on the west. It is not certain, however, that it is diamondiferous for the whole of that extent. But it may be fairly assumed that it is so throughout the area included between the easternmost and westernmost diamond mines, that is, from Majgama in Patarkechar territory, east of the valley of the Bagain, up to another locality also called Majgama in Panna territory, 12 miles south-west of Panna. Between these limits the area under which the diamondiferous layer could be reached by shafts of less than 250 feet is over 100 square miles, and this estimate must be nearly doubled if the layer maintains a sufficient portion of gems up to Kishengarh and Bambia. The matter is so clear that there seems no reason why the work should not be undertaken by the State. Further prospecting cannot disclose anything new. The only preliminary work to be undertaken is that of making a few excavations. If these yield satisfactory results, a moderate capital should suffice to start systematic work.'

It is not generally appreciated that about 80 per cent of the world's output of diamonds is used for industrial purposes, or that the diamond by reason of its unequalled hardness and resistance to abrasion ranks high in the list of minerals of strategic importance.

In the pre-war years, 1934-8, the average annual world production is believed to have been about 8,055,000 carats, valued at £6,324,000; for the five years ending 1951, the annual average was about 13,186,000 carats: moreover, throughout these five years there has been a marked rise annually, from 10,047,000 carats in 1948, to the highest production ever recorded of 16,780,000 carats in 1951. The sales of diamonds in 1951 brought a total of £65,058,000 and in 1952 of £69,662,000, divided as to £45,770,000 for gems and £23,892,000 for industrial stones.

Industrial stones, in the words of Dr R. S. Young, Director of the Diamond Research Laboratory at Johannesburg, South Africa, are diamonds which 'on account of imperfections such as inclusions, spots, cracks, coatings, inferior crystal form, or dark colour, cannot be economically cut and utilized as gem stones'. Many industrial diamonds belong to the class known as 'bort', described as a grey and greyish black to black variety: others, termed 'carbonado', are greyish black to black, cryptocrystalline, compact kinds which are said to be particularly suitable for such purposes as diamond drilling owing to their lack of pronounced cleavage directions. Carbonado is in such demand that its price approaches that of the gem stones. Neither of these varieties have been reported from India, and, in any case, if found by the earlier miners were probably thrown away.

For all purposes where a material of superlative hardness is needed, the industrial diamond has no equal, whether it be set in a precision tool in a lathe, in the matrix of a grinding wheel, or in the periphery of a metal disc for sawing through rock, metal or ceramic material. The superfine finish obtained by the use of diamond lathe-tools is said to be unsurpassed, and they are employed in the turning of aircraft engine parts, bearings for electrical meters and other scientific instruments, timing devices, micro-gears, typewriter platens, watches and so forth.

The diamond drill of the mining engineer consists of hollow steel rods supporting a coring crown—a metallic ring set with diamonds around its face. On rotation of the rods the diamond-armoured bit can cut through the hardest rocks, leaving a core of the material penetrated in the hollow stem, from which it can be removed as required for examination and assay. Such drills were employed in the developmental stages of the Indian copper mines. Non-coring, or blast-hole drills, set with diamonds over the whole surface of the metal bit, are also employed; not for exploratory, prospecting work but in later mining operations. Small diamond drills also have many uses both in engineering and in a number of manufacturing processes as well as in dental surgery.

In the preparation of diamond dies for fine wire-drawing, a hole is drilled through the stone tapering towards the centre. Its resistance to abrasion enables large quantities of wire, of copper, brass, tungsten or other metals, to be produced with accurate,

predetermined diameters, without appreciable wear of the stone itself. Abrasive wheels made of carborundum or artificial corundum are smoothed and resurfaced by means of diamond dressing tools and truing wheels. The glazier's diamond, used for cutting glass, is a familiar object, and in the engraving or inscribing of glass, porcelain and metals, diamond-pointed instruments are employed. Diamond points are also used for cutting the grooves in gramophone records, in dictating machines, and as gramophone needles. Diamond powder is employed in the sawing and polishing of both gem and industrial diamonds.

Some 97 or 98 per cent of the world's diamonds come from Africa; thus in 1951, the Belgian Congo produced about 10,565,000 carats, mainly of industrial grade; the Union of South Africa, 2,256,000 carats; the Gold Coast, 1,600,000 carats; Angola, 751,500 carats; South-West Africa, 478,000 carats; Sierra Leone, 476,000 carats, while smaller quantities came from French Equatorial Africa, French West Africa and Tanganyika. In South America, the same year, Brazil had an estimated output of 200,000 carats, while Venezuela and British Guiana also contributed to the total.

The world's commercial supplies of diamonds of all kinds come exclusively, therefore, from countries which geologists include in Gondwanaland, the great southern continent which embraced parts of South America, Africa, the peninsula of India and Australia, between Upper Carboniferous and Jurassic times. It is remarkable and regrettable that India, which gave its name to Gondwanaland and which supplied all the world's gem diamonds for so many centuries, should now occupy so lowly a position as a producer. It is certain, however, that unless new ground is broken and age-long, casual, small-scale practices displaced by such modern methods as are now in process of introduction in Vindhya Pradesh, India can neither satisfy her own demands for gems and industrial diamonds, nor enter the markets of the world.

According to the 27th Annual Survey of the Diamond Industry, by W. F. Foshag and G. Switzer, of which a summary appeared in *The Gemmologist*, Vol. XXI, No. 256 (1952), there are from 300 to 500 workers engaged in the diamond-cutting industry in India, mostly in Bombay, though both cutting and polishing are also carried out in Surat, Navsari, Panna, Jaipur, Tiruchirapalli (Trichinopoly) and Madras. As the importation of diamonds is prohibited at present, the industry depends on Indian-mined stones and the recutting of old ones. Most of the diamond workshops are manned by family groups, but a few of them have been partly modernized.

RUBY

'It is the rubies of the Burmese Empire which are its greatest boast, as both in brilliance and clearness they are the best in the

world,' wrote Father Sangermano, who lived in Ava between 1783 and 1806. The earliest reference to the mines is in a royal edict of 1597, but at that time ruby mining was an old established industry. They are alluded to in the writings of various early European adventurers in the East, including Stefano (fifteenth century), di Varthema (1496), Barbosa (1501-16), Frederic (1569) and Fitch (1586). The earliest record of a visit to the mines was not given until 1833, by Père Guiseppe d'Amato, though they have undisputedly yielded the greater part of the rubies used in the world's jewellery, including the finest specimens known. Rubies do come on the market from other countries, notably from Siam and Ceylon, but the clear, limpid, deep crimson-red of a fine Mogok ruby is incomparable. The shade which is most prized is a transparent carmine-red with a faint suggestion of a bluish tint which yields the famous 'pigeon's blood' stone, the term being derived from the Hindustani, as Indian lapidaries compare the colour of a faultless ruby with the blood-red colour of a living pigeon's eye. Compared with the Burmese stones, Siamese rubies are generally darker in colour, inclining to a claret-red, or with a purplish-brown tinge, while Ceylon rubies are, as a rule, much paler in colour with an uneven distribution of tint which may appear as spots and streaks of blue in the stone itself. Many Ceylon specimens are better termed pink sapphires than ruby-red gems. A delicate, whitish sheen on the surface of a cut stone is a characteristic of some Burmese rubies. It is caused by the reflection of light from the ends of the extremely fine and numerous systems of microscopic canals, arranged in the internal structure of the gem in planes parallel to the prismatic faces. Such stones when cut *en cabochon*, parallel to their basal plane, exhibit a six-rayed star, provided that all three sets of canals are originally present.

The Mogok Stone Tract is an area of over 600 square miles in the Katha district of Upper Burma, and the productive region lies towards its eastern limits. It is made up of gneisses and associated rocks of Archaean age with many intrusives of varied types. Important associates of the gneisses are the crystalline limestones from which the rubies and spinels have been shed into the detrital and alluvial deposits and from which they are won. The Burmese miners sought for the stones by tunnelling along the lines of fissures in the limestones, by opening excavations in the hillside deposits, and by sinking narrow shafts into the alluvial floors of the valleys to reach the gem-bearing gravel below. In 1889, a lease of the Stone Tract was granted to the Burma Ruby Mines Ltd, and this concern carried on systematic operations with varying fortunes in the alluvial deposits, mainly in the Mogok valley itself, but also at Kathe and Kyatpyin, until June 1931. The gravel was dug or washed out of large open-casts, classified into different sizes and treated by pulsators and tables to produce a clean concentrate from which the gems were picked by hand.

During its active career the Company is believed to have recovered gems to the total value of approximately £2½ millions, and those in the best position to form a judgement think that the Burmese miners probably found stones of a more or less equal value. No trustworthy statistics are available of the production of the indigenous miners, as the Government was only concerned with the collection of the fees levied for the grant of mining licenses, and there was no obligation on the miners to report the quantity or value of their finds. Such a statutory contract would in any case have proved unenforceable under prevailing local conditions.

It has been authoritatively stated that about 85 per cent by weight of the total stones recovered by the Company were rubies of various grades and that nine-tenths of these were of poor quality, too dark or too light, too flawed or too silky or otherwise defective to be regarded as really good stones. At the same time there was an outlet for most of them at cheap rates, the principal market being in India and mainly in the South. The remaining 15 per cent of the total output consisted of blue or star sapphires and a smaller quantity of fine spinels excluding poor spinels, fancy sapphires and other gem stones. The local classification of the rubies is too elaborate to be described here but an account of it is available in an article by Halford Watkins, for many years Deputy Agent of the Company, in *The Gemmologist*, Vol. I, No. 12, 1932, where the names and qualities of upwards of 30 separate varieties are given. The greater proportion of the rubies are small, but from time to time exceptionally large stones have been found.

It is a commonplace remark that the ruby is a more valuable stone than the diamond, but this only applies to perfect rubies of large size. A fine ruby begins to rival a diamond of the same class when it is about 2 carats in weight, but beyond that the ruby exceeds the diamond in value. Diamonds of large sizes are comparatively common, and 10-carat stones can be had in abundance by those prepared to pay for them, but a perfect ruby of 10 carats is a most exceptional rarity. Large rubies of superb quality are perhaps the most valuable minerals known to mankind. Two stones, brought to Europe from Burma in 1875, weighed 37 and 47 carats; when recut they weighed 32·3 and 38·6 carats, respectively: it is recorded that the smaller stone brought £10,000 and the larger one £20,000. A stone weighing 77 carats in the rough, found by the Company in 1889, was valued at Rs 4 lakhs; another weighing 9 carats was sold for Rs 27,000, and cut to 6 carats, sold for £2,000; yet another of 21 carats, cut to 13 carats, brought £7,500. A ruby from the Burmese royal collection, weighing 36 carats, was sold by King Mindon Min for £30,000. The great 'Peace Ruby' of 1919, a superfine stone of magnificent colour, weighed 42 carats and except for a fracture estimated to necessitate the removal of a slice of about 8 carats, was in every way perfect; it was sold in the rough, on the spot, in Mogok, to an Indian dealer

for Rs 3 lakhs. In October 1932, a fine stone weighing about 30 carats and valued at £7,000 was found in a Burmese working at Mogok, and in February 1933 a 20-carat stone, recently obtained from Burma, was cut in Hatton Gardens to a weight of $7\frac{1}{2}$ carats and was valued at nearly £10,000. The market for rubies is a world-wide one, but it is extremely sensitive to general economic conditions, enjoying prosperity in times of plenty and industrial activity, and slumping when the purchasing power of the nations decreases. The trade has suffered too from the competition of synthetic and reconstructed stones, but these are distinguished easily enough by the initiated and the discriminating buyer always prefers the natural gem. Geological investigation has proved that the resources of the Stone Tract are by no means exhausted and the production of stones by the old, ancestral methods can continue indefinitely as long as any demand exists.

Rubies were obtained at one time from clay-filled hollows and fissures in the crystalline limestones of the Sagyin Hills which rise abruptly from the alluvial plain on the left bank of the Irrawaddy, some 16 miles north of Mandalay. Another ruby-bearing tract exists near Naniazeik, in the Myitkyina district, where the stones were obtained from the detritus of crystalline limestones which are surrounded by intrusive masses of granite, but no mining has been done at either of these localities for many years.

SAPPHIRE

The sapphires of Kashmir, like the rubies of Burma, form an exclusive class of their own. The appellation 'Kashmir', often attached to any fine sapphire in the jewel trade, regardless of its geographical origin, is some indication of their outstanding qualities. The best amongst them are an intense cornflower blue, with a rich velvety lustre and a tenuous milkiness spreading over the surface and adding greatly to the charm of the stone. Halford Watkins, a specialist of unrivalled experience, stated that this is an appearance entirely characteristic of sapphires of Kashmir origin, not to be met with in any others, adding that they are perfect night stones and that 'a fine Kashmir star sapphire is a thing of the most exquisite beauty but unfortunately very rare indeed'.

The mines are $2\frac{1}{2}$ miles west-north-west of Sumjam, in the Padar area of Zangskar, at a height approaching 15,000 feet, on the southern slopes of the Zangskar Range, below the Umlasi Pass, and the whole area is under snow for the greater part of the year. Kaolinized pegmatites, intrusive into garnetiferous biotite and hornblende gneisses with some crystalline limestones and amphibolites, bear corundum-sapphire, black, red, green and brown tourmaline, green euclase and garnet as accessories. The corundum contains patches of sapphire varying from pale blue to azure in colour, and it is found not only in lenticles of decomposed

feldspar *in situ*, but also in the detritus of the veins shed on to the lower ground of the surroundings.

Discovered by accident about 1881, the gems first came on to the Indian market about 1882, in which year Mallet examined many of them: 'the mineral', he states, 'is partly bluish-white and translucent, partly transparent and of a rich blue colour, the two varieties being irregularly intermixed. It is the latter, of course, which constitutes the sapphire, the bluish-white part being rather corundum. A large proportion of the crystals are milky, with variously-sized portions of sapphire irregularly scattered through them. Others, again, are mainly sapphire, and are only milky here and there. More rarely the colour shades into yellow, brown or red.' La Touche visited the workings in 1888, and for some years after this the Kashmir Durbar derived a considerable revenue from them before they were abandoned under the erroneous impression that they were worked out. In 1906, however, work was restarted by the Kashmir Mineral Company, and at first several valuable stones were obtained, one of them being sold for £2,000, but by 1908 the inaccessibility of the location and its rigorous climate proved too much and operations ceased once more. In 1927 the area was again worked with good results, 11 cwt. of 'corundum' being obtained, and about 1930 it was still being policed on an elaborate scale to prevent theft by 'adventurous gangs of hardy smugglers who have recently sprung up and come to regard these regions as their own particular hunting-grounds' (Middlemiss). Systematic work commenced again in 1933 and from that time until the end of 1938 the average annual production was 641,656 carats of sapphires, according to the official returns. The finest stones were always stored in the State Treasury at Jammu: La Touche records how he saw crystals there 5 inches in length by 3 inches in breadth, and though none of these were uniformly coloured, but shaded off into white at either end, still, some very fine gems could be cut from them. The few specialists who were privileged to see this collection at later dates have all declared that it was very large in quantity, both of rough and cut stones, while the choicest specimens were probably unequalled for size and for purity and beauty of colour.

Sapphires accompany rubies in the gem gravels of the Mogok valley in Burma, but the best stones have been obtained about Kathe and Gwebin, places about 8 and 16 miles west of Mogok itself, and in a tract of country stretching north-east from Gwebin towards Bernardmyo. Surface workings at Chaunggyi, 4 miles north of Mogok, have also yielded some good stones. The matrix of the ruby is the local crystalline limestone. The sapphire, sometimes found intergrown with feldspar, may come from the pegmatites and nepheline-corundum syenites. The rubies when they exhibit their crystalline form are practically always combinations of hexagonal prisms and basal planes, sometimes with subsidiary

rhombohedral faces and generally of a tabular habit. Sapphire crystals, on the other hand, always show steep pyramidal faces, whereas rubies exhibiting them are exceedingly rare.

The blue shade of the Burmese sapphire varies greatly from the lustrous, strong royal blue and the deep cornflower colour of superfine stones (though none of them possess the delicate mistiness of their Kashmir rivals), through varying nuances of gem quality to the paler blues of the cheaper stones. Among the fancy varieties are indigo, purple, greenish-blue, yellow and colourless stones (the so-called 'white sapphires'). It has been stated that Burmese sapphires as a whole are usually too dark for general approval, but this is quite incorrect; next to the Kashmir sapphires they are unsurpassed. Speaking generally, Ceylon sapphires are too light and Siamese sapphires too dark, and it is more than probable that many of the best 'Ceylon' stones first saw the light of day from the mountainsides of the Mogok Stone Tract. Mogok also supplies many excellent star sapphires, the stellate opalescence being much commoner in the blue varieties of corundum than it is in the red ones, so that star sapphires are much more frequently seen than star rubies. Though the rubies occur in much greater numbers than the sapphires in the Stone Tract, the latter are often of considerably larger sizes. For example, stones of 630 and 293 carats were found at Kathe, in 1930; another weighing 514 carats was discovered in a Burmese working at Mogok, in December 1932; but probably the record stone was scratched from grass roots near Gwebin, on 12 August 1929 by a group of labourers. It was a water-worn, doubly truncated bipyramid of superb colour, weighing 958 carats; sold on the spot for over £13,000, it was bought by a New York dealer and later cut into nine magnificent sapphires, weighing 66.50, 20.25, 20.00, 13.11, 12.25, 11.33, 11.11, 5.50 and 4.33 metric carats respectively.

SPINEL

Spinel is an aluminate of magnesium, $\text{MgO} \cdot \text{Al}_2\text{O}_3$, and when in this pure condition—an extremely rare occurrence—the mineral is colourless. But either of the two oxides of which it is composed may be replaced by others of similar valency—magnesia by the oxides of iron, zinc or manganese; aluminium by ferric iron and chromium, the mineral chromite, $\text{FeO} \cdot \text{Cr}_2\text{O}_3$, being the end member of the series which commences with the magnesia spinel. In this replacement process is to be found the explanation of the unusual colour range which the gem possesses.

The concentrate from the gem-bearing gravels of Mogok, whether recovered in the miner's pan or the washing machine of the European Company, contained spinels of many kinds. As long ago as 1850, Dr Mason pointed out that spinel was one of the constituents, and in the samples of gem sands examined by him the

mineral made up more than three-fourths of the whole mass. 'A single handful will contain specimens of every shade—black, blue, violet, orange, amber-yellow, wine-yellow, brown and white. Many retain their original crystalline forms; some have the fundamental form of the species, a perfect octahedron; but many others have some of the secondary forms, among which it is not uncommon to see twins with three re-entering angles, formed by two segments of the tetrahedron truncated on the angles and joined together by their bases.' Similarly, Dr A. W. G. Bleeck, describing the gravels of a small stream once washed for rubies, near Manwe, Myitkyina district, states that a handful of spinels can be collected there in a few minutes, in octahedral crystals, often twinned and varying with the pellucidity from almost opaque dark green to a rare, bright, translucent red.

Mason distinguished the blood-red form as the spinel ruby, the rose-red as the balas ruby, an orange-red kind as rubicelle and a violet variety as the almandine ruby. He also mentioned 'the dark blue or blackish varieties called ceylonite or pleonaste'. These dark green to black spinels are well-known accessory minerals in Indian pyroxenites and they owe their colour to the partial replacement of alumina by ferric iron, Fe_2O_3 . Gahnite, the zinc spinel, $\text{ZnO} \cdot \text{Al}_2\text{O}_3$, of a vitreous, shining, greenish black colour and only transparent in thin fragments, when it is a dull, opaline green, has been described from Tummalatalupur, in Nellore. A closely related spinel which has part of its zinc replaced by iron and manganese, known as dysluite, occurs in resinous, black, irregular masses and crude octahedra, in the claeolite-syenite gneiss of the Sivamalai area, Coimbatore. The black spinel, hercynite, in which the magnesium is entirely replaced by ferrous iron, $\text{FeO} \cdot \text{Al}_2\text{O}_3$, was found in lumps and nodules with corundum, near Palakod, Salem district, Madras, by the late Rao Bahadur Sethu Rama Rau. The black or nearly black spinels are not attractive stones, though it is said that they are sometimes used for ornamental wear.

The gem varieties of the mineral are mainly confined to transparent specimens of varying shades of red, blue and violet. The colour of the former is believed to be due to a slight replacement of aluminium by chromium and of the latter two to the presence of ferrous iron. The red spinels of Mogok may be of rose, scarlet, Indian red, or various shades of pink, but the most splendid of them all is a rich deep-red stone which rivals the ruby in beauty, although large and perfect specimens are worth but a fraction of its value. A. H. Morgan, the Agent of the Burma Ruby Mines for many years, wrote: 'I have seen a number of very fine spinels but none of a higher value than £100.' Here Mr Morgan was referring to notable specimens of exceptional size; for small stones the disparity is very marked. Before the last war, when fine rubies weighing two to three carats were valued at from £120 to £350, fine

red spinels of equal weight could be obtained for from £6 to £15. The octahedra of the cubic system in which spinel occurs are often found in a perfect condition and are sometimes mounted in some forms of jewellery in their pristine condition. The Burmese miners attribute their natural lustrous polish to supernatural agencies, that is to the work of the *nats*, or denizens of the unseen world, so, while water-worn spinels are known as *anyan*, red spinels in this particular and remarkable form are termed *anyan-nat-thwe* or 'spinel cut by the spirits'. After cutting, the deep red spinel is easily, and it must be admitted, frequently mistaken for the ruby, on casual inspection by eye alone, so much so that experienced dealers in Mogok, though ready to assert that such a differentiation is perfectly easy, were the first to produce a dichroscope in cases of doubt. It provides an infallible test, for rubies are dichroic and spinels are not.

The fine, light blue spinels cut at Mogok, though they are not particularly common there, may be gahnospinel, though their chemical composition does not appear to have been investigated. They possess a peculiar, though not unpleasing, steely-blue character of their own, and once handled are not likely to be mistaken for sapphires. Mogok also produces reddish-purple and violet stones, but the best violet spinels come from Ceylon.

TOPAZ

Topaz is a fluo-silicate of aluminium, $\text{Al}_2\text{F}_2\text{SiO}_6$, in which part of the fluorine may be replaced by hydroxyl, OH. It crystallizes in the orthorhombic system, commonly in vertically striated, eight-sided, rhombic prisms, terminated by pyramids and domes and often by a basal pinacoid as well. Doubly terminated crystals of any size are very rare. The mineral has a perfect basal cleavage and has to be handled with care both during cutting and afterwards; its very wide range of colours includes many shades of yellow, brown, blue and pink, though many of the latter are heat-treated, brown stones of Brazilian origin.

Although topaz was used as a jewel in India at least as early as the fifth century B.C., it was not until 1900 that it was first recorded in Indian geological literature, when colourless crystals were detected in a parcel of gem stones from the Katha district sent by the Government of Burma to the Geological Survey Office in Calcutta for determination. The so-called 'oriental topaz', referred to by earlier writers on Indian gems, is, of course, the yellow sapphire—a variety which is still known in Ceylon as 'king-topaz'. The saffron-yellow topaz of Ceylon is also termed for some obscure reason 'Indian topaz', though yellow 'topaz' from India proper has proved on examination hitherto to be yellow rock crystal, or citrine.

Topaz was found later in association with fluorite, in a cassiterite-bearing vein at Hermyingale, and in a granular form with alluvial tin-stone, at Taungthonlon, both in the Tavoy district, Burma. Topaz occurs freely with certain rocks of the 'kyanite belt' of Singbhum, though whether they will furnish gem quality material remains to be seen. In the vicinity of Kanyaluka, in the Dhalbhum subdivision, there are veins and patches of pale blue topaz in boulder outcrops of quartz-kyanite rock. It is also common in quartz-kyanite rock, south-east of Bakra, while at Ghagidih, also in Dhalbhum, a topaz rock, apparently continuous with kyanite rock, has yielded crystals 4 or 5 inches long, though too impure for gem cutting. Topaz granulites passing into topaz-muscovite schists occur at Lapsa Buru, in Kharsawan, where a coarse muscovite-topaz rock of a pegmatitic appearance forms veins and segregations in the granulite of South Hill. Pink dumortierite as well as tourmaline occur in places in the same belt, the former being particularly abundant at Mohanpur. Dumortierite of a beautiful lavender colour has also been reported by S. K. Chatterjee as occurring in quartz veins and in kyanite-bearing rocks of the Mogra and Girola areas, Bhandara district, Madhya Pradesh. Veins of quartz-dumortierite rock occur one mile west 10° south of Usekheda, and bands of dumortierite-topaz-kyanite-muscovite schist between Dahegaon and Murjhar. Dumortierite is a hydrated borosilicate of aluminium and when polished is said to make an attractive ornamental stone, its gem varieties coming mainly from California and Madagascar. It is mentioned here because of its association with topaz in both Bihar and Madhya Pradesh.

Slightly water-worn crystals of topaz, sometimes exhibiting the rare double terminations, and either perfectly colourless or with a faint yellowish tinge, are found in the gem gravels of the ruby mines of Mogok, but the finest specimens yet produced were obtained when the great pegmatite dyke at Sakangyi, near the 42nd mile post on the Thabeitkyin-Mogok motor road, was mined for rock crystal about 1923. Most of them were colourless, but fine yellow and blue examples of gem quality were also obtained. A magnificent specimen measured by one of the present writers was of a clear, pale amber colour, a simple prismatic type crowned by a sharp pyramid; weighing over 10 lb., it was 6.7 inches in height, 5.6 inches in width and 4.2 inches in thickness. Another paler yellow example was of much the same size. Smaller topaz crystals, exhibiting many complex forms, must have been very abundant and could be obtained locally in quantity years later; usually under one inch in height, they were ideal specimens for the crystallographer, but without colour and of no interest to the jeweller. Colourless topaz is sometimes cut in brilliant or step-cut styles in Mogok, but it is worth little more than the cost of cutting and is referred to derisively as the 'Mogok diamond'.

TOURMALINE

Tourmaline, the complex borosilicate of aluminium, together with the alkali metals, iron or magnesium, derives its name from the Singhalese word *turmalli*, which is also used to describe the yellow varieties of zircon. It crystallizes in the rhombohedral class of the hexagonal system and is hemimorphic, the two ends of its prismatic crystals, which may be three- or six-sided, being therefore dissimilar. It is a common accessory mineral in many types of acid igneous rocks and pegmatites, as well as in veins with metallic ores and in various metamorphic rocks. Common tourmaline is black and opaque as it is rich in iron, but the alkali and magnesian tourmalines are usually transparent and coloured, and it is from them that the gem tourmalines are derived.

Rubellite or red tourmaline, an alkali variety, is the most prized member of the group, and it may possess any shade from a near-ruby colour to rose-red and pink. Pink tourmaline was mined sporadically under Chinese supervision for over two centuries, until about 1910, near Maingnin, in Mong Mit, which adjoins the Mogok Stone Tract of Burma on the north. The matrix of the gems was a thick, decomposed pegmatite, and the methods followed were those of the ruby miner. In 1930, specimens of rubellite from this locality still existed in the stocks of some of the stone dealers in Mogok, but they were growing scarce and becoming rather costly. Lovely multicoloured, sheaf-like growths of columnar tourmaline crystals, each terminated by a squat pyramid, pressing close together in divergent form from a common base, and of varying shades of red, purple and green, were also seen in Mogok about that time, but their locality is not known.

Namon, in the Salween valley of Karenni, used to supply transparent and brilliant, dark emerald-green crystals, varying in size from that of a pea to a bean, which were for a time successfully disposed of in Rangoon as emeralds. According to Middlemiss (1900) they are shed from crystalline limestone into a sandy surface clay which was mined by pitting and then washed to recover the gems. These were all independent crystals, bounded by brilliant faces, chiefly of the prism and rhombohedron, and a few were actually found *in situ* in the crystalline limestone—really a handsome white marble, which lay below the clay.

The mica-bearing pegmatites of Rajasthan have, so far as is known, furnished no useful, transparent red, green or blue gem tourmalines, but mention may be made of the gigantic dark green to black crystals, with well-developed end faces, up to 12 feet in length and 18 inches in diameter, which are to be found at Bhunas, in Mewar, and of others 3 feet long and 10 inches in diameter occurring at the Makrara beryl mine in Ajmer.

Blue and green kinds occur at Lapsa Buru, Kharsawan, Singhbhum, and blue and green varieties have been found in the mica-bearing pegmatites of the Hazaribagh district. A transparent

green tourmaline, sometimes of gem quality, is associated with dark blue indicolite in such a pegmatite at Manimundar, for example: some of the crystals from this place being blue internally with an outer skin of a green colour. At Jhanda Buru, in Chota Nagpur, there is a white aplite traversed by streaks and lines of blue tourmaline.

A pegmatite between Mogra and Medi, in the Chhindwara district of Madhya Pradesh, carries tourmaline of various shades of black, brown, green and pink, as well as light orange-yellow garnet, but the material exposed at the surface is not of gem grade.

Light green tourmaline crystals, transparent, very thin in proportion to their length, seldom reaching more than 2 inches with a breadth of about $\frac{1}{8}$ inch, occur in a granite vein about one mile from the Kashmir sapphire mines, where they thickly encrust and penetrate large quartz crystals. Rubellite with the tint of the pomegranate and small transparent brown tourmalines also come from the same locality.

ZIRCON

Zircon, the natural silicate of zirconium, ZrSiO_4 , crystallizes in the tetragonal system, and its hardness, high refractive index and great dispersive power make it a popular gem stone. 'Colourless stones rival even diamond in splendour of brilliance and display of fire,' writes G. Herbert Smith. 'Zircon is probably the stone most able to simulate gem diamond, especially in artificial light,' states R. Webster. 'When well cut and polished, with their large dispersion, colourless and pale zircons may closely approximate to the diamond in general appearance,' adds J. F. Halford Watkins. The colour range of the species is remarkable and covers many shades of red, brown, green, orange, yellow, blue and colourless, but most of the sky-blue and colourless stones are obtained by the heat treatment of yellow and brown varieties. According to Wadia and Fernando, the name 'hyacinth' is applied to the clear, transparent, red, orange, brown and yellow stones, while the name 'jargon' is given to all other coloured and transparent gem varieties. The term 'Matara diamond', bestowed on stones rendered artificially colourless, is misleading and ought to be discarded.

With the exception of a locality near Kedarnath, in Garhwal, whence a number of fine red stones are said to have come, and of a pegmatite at Appiyode, in the Eranial taluk of Travancore, where red and greyish-white crystals which are seldom transparent have been found, the presence of zircons of gem quality has not yet been proved in India. The best zircons come from Ceylon, but the gem gravels of Mogok and certain deposits in Siam are important sources of supply. Although the zircons of Mogok and of other valleys in the Stone Tract of Burma are now obtained from alluvial deposits, their original home was probably the local crystalline

limestone and they are usually found as well-formed, clear crystals exhibiting few signs of wear. They are generally in the form of short, squat, square-sectioned, four-sided prisms, doubly-terminated by a similar pyramid, or by a combination of two or more of them. Sometimes the edges are more or less abraded, but water-worn pebbles of zircon are rare. Transparent green and greyish green tints are the commonest natural colours, but brownish green, reddish brown, greenish yellow and yellow stones also occur.

Natural zirconium silicate is never pure, containing as it does small quantities of other elements such as iron, titanium, calcium and hafnium; furthermore, zircons are often radio-active, sometimes markedly so, owing to the presence of uranium or thorium. This radio-activity is said to be responsible for the breakdown of the lattice structure of some crystals, resulting in a marked decrease in their specific gravity and refractive index, though in the case of Mogok zircons, according to Dr Oscar Weigel, no such alterations have taken place, even when they exhibit a radio-activity equal to that which has demolished the internal structure of some Ceylon crystals, and reduced them to the 'low' or 'metamict' type, composed of amorphous silica, SiO_2 , and amorphous (or micro-crystalline) zirconia, ZrO_2 . Most Mogok zircons belong to the 'high' type, that is to say they are completely crystallized, normal, zirconium silicate; the others belong to the intermediate class. Characteristic of many Mogok stones are the remarkable absorption spectra which they exhibit, a useful help in the identification of cut gems, for the refractive index of zircon is too high to be measured on the instruments usually employed for the purpose.

Zircons are not expensive gems: in 1933 they could be bought in London at prices ranging between 2 and 40 shillings per carat, depending on the size and colour of the stone itself, but by 1939 the price had advanced to a minimum of 10 to 15 shillings per carat for small stones, up to about 30 shillings per carat for fairly large blue and red varieties, and 15 shillings per carat for colourless stones weighing about 4 carats. Owing to its high specific gravity, a zircon, say, of one carat in weight, is appreciably smaller than a diamond of equal weight.

AQUAMARINE OR BERYL

Aquamarine is the transparent bluish or bluish green variety of beryl, a silicate of beryllium and aluminium, $\text{Be}_3\text{Al}_2\text{Si}_6\text{O}_{18}$, which crystallizes in the hexagonal system, the same mineral which when of an intense, grass-green colour becomes the emerald. Beryls were produced in India about 400 B.C. according to S. Ball: Strabo mentions their use in the ornamentation of Indian drinking cups (45 B.C.-A.D. 21) and Pliny regarded India as the chief source of the stone in his time. Of more substantial evidence are the beryl

ornaments found in the Bhattiprolu stupa, dating from the Andhra dynasty (220 B.C.-A.D. 236).

Stones of blue and sea-green shades were mined in the early decades of the nineteenth century at Padyur, in the Coimbatore district of Madras, where they occur in a drusy vein of graphic granite intrusive into mica schist. An account of the workings at this place was given by Leschenault de la Tour in 1822. Slender, pale blue crystals, over two inches in length, occur in the great pegmatite vein at Sakangyi, Katha district, Burma. A yellowish-green variety occurs with the more usual bluish green kind in pegmatite veins near Melkote, Mysore.

As a general rule, the beryls of the mica-bearing pegmatites of India, in which they often attain huge dimensions, are too fissured and flawed and of too washed-out a colour to be of any value in the gem trade. As an exception to this, however, some beautiful aquamarines have come from the mica mines, $1\frac{1}{2}$ miles west of Saidapuram, Nellore.

Coarse beryl is mined on a large scale in Rajasthan for the sake of its metallic content, and the prodigious size of some of the crystals obtained in that region has been referred to under **BERYLLIUM**. In some crystals, up to about 9 inches long and about 3 inches across, colours are displayed very different from the common blue and greenish blue shades. These are of orange and amber, pink, brown, reddish brown and even black colours but, unfortunately, most of these crystals are cloudy, only the very small ones being water-clear. It is said, however, that small pieces of gem quality can often be broken from the others, particularly those of pale amber and aquamarine tints. They are occasionally made use of by the local lapidaries, but are not in much demand. Some of the necklaces of pale blue and greenish, large, semi-transparent, irregularly clouded beads, sold by jewellers in Jaipur, may be made from local material, according to Dr A. M. Heron. The pink and red beryls from Mewar, Kishangarh and Lohargal, in Ajmer, merit further attention, for the lovely gem known as morganite is a pink or rose beryl which owes its colour to the presence of small amounts of lithium. 'Golden beryl' is the name given to the more intensely coloured yellow varieties, referred to in the trade as 'heliodor'. The paler yellows have no particular interest, but the deeper coloured, bright examples have a value of their own. Whether Rajasthan can furnish material of this class has still to be determined.

Aquamarines were discovered in 1915 near Daso, in the Shigar valley of Ladakh, Kashmir, where biotite gneiss is traversed by pegmatite veins containing quartz, orthoclase, a bite, tourmaline, garnet and beryl. The best crystals of gem quality come from drusy cavities in the central, feldspathic portions of the veins, where they form transparent prisms from $\frac{1}{2}$ to $1\frac{1}{2}$ inches in width and 2 to 3 inches in length. In colour they are a vivid greenish blue and, as

cut stones, tend to be delicate and pale in tint with a noticeable limpidity, especially apparent in artificial light. This is the best that can be said of the Daso aquamarines and, in the words of C. S. Middlemiss, who opened up the workings with Lala Joti Parshad, 'it is no use arguing against the vagaries of fashion, and inasmuch as these Daso aquamarines seldom show great depth of colour, in this one respect they fall short of the highest standards of excellence now in vogue. This will in some measure detract from their value in the markets of the world'. This may well be the explanation of the fact that though 3.75 cwt of beryl were removed from the area in 1915, and 4.13 cwt in 1916, the last recorded output was of 55 lb. in 1921. The deposits themselves gave promise of great richness and extension, in fully exposed outcrops, in a country where soils and vegetation are very restricted. Daso itself is situated on the right bank of the Braldu river, a few miles above its junction with the Shigar, and it is known that aquamarines have also been found at other localities, further up the Braldu and Basha valleys, and also in the Rondu neighbourhood.

EMERALD

The emerald is the rare, richly verdant green variety of beryl; fine, transparent specimens of which are said to be the most desirable of all precious stones and then, like the best rubies, surpassing even the diamond in value.

Emeralds have always been held in high esteem in India and there are said to be references to them in the *Mahabharata*. The *Agastimata*, a treatise on gem stones, dated earlier than the tenth century A.D., recognizes eight classes of emeralds, the best of which must be transparent and without dust, 'pure as a drop of water on a lotus leaf', of a velvety reflection, and so coloured that when exposed to the sun on the palm of the hand, it tints its whole surroundings. Such a stone would indeed be remarkable, for unflawed emeralds more than a few carats in weight are almost unknown, though, as R. Webster has observed, an eye-clear stone is far from an impossibility.

In the absence of any known Indian deposits, students of such subjects have hitherto believed that the stones were imported from Egypt, perhaps by way of Ethiopia, and later perhaps overland from Siberia. It should be added that the ancient emerald mines of the Jebel Zebara and Jebel Sikait, in Egypt, were probably worked some 2,000 years before the Christian era, and doubtless were the source of the stones used in much ancient and medieval jewellery. The discovery of emeralds in Udaipur, Rajasthan, however, proves that the stone does exist in India, and it may well be that in earlier times other deposits, long exhausted and forgotten, contributed their quota to the home market, though this does not rule out the contemporaneous existence of an extensive import

trade. Coming to more recent times, it is known that the imports of emeralds from the London market were on a considerable scale 70 or 80 years ago, and in later years still stones were obtained from Colombia and the Ural deposits. Writing in 1935, Vanechand D. Zaveni commented on the demand in India for the rough stones which, imported into Bombay, Calcutta and Madras, eventually reached Jaipur for cutting, where, he added, many of the gem dealers have vast foreign connexions. This demand continues, especially for the cheaper and lighter coloured stones from other producing territories. Previous to 1948, India was the chief market for the bulk of the South African emeralds from the Leysdorp district of the Transvaal.

The Kalaguman emerald mine lies nearly 9 miles east of Charbhujia railway station, in Udaipur, and has been worked as a large open-cast since 1945, though underground methods have been tried and abandoned. The country rock consists of hornblende schist and the emerald crystals are distributed at random in vein-like bodies of soft, talcose, biotite schists containing occasional pockets of actinolite needles. These bearing-bodies, or bands, range from $1\frac{1}{2}$ to 5 feet in thickness, between hornblende schist and an altered rock of a peridotite type. There are also abundant intrusions of pegmatite in close proximity to the emerald-bearing schists. Up to the end of 1951, 2,567 lb. of emerald of run-of-mine grade had been produced here, and the sale of stones up to November 1951 had totalled Rs 7,78,261.

The Rajgarh emerald mine is about 15 miles south of Ajmer itself, in Ajmer-Merwara, the nearest railway station being Lachpura, 3 miles north-east of Rajgarh. It lies on the Aravalli Schistose Complex and the stones again occur in soft, talcose, biotite schist, associated with altered peridotites and intrusive granite and pegmatite. Quarrying commenced here in 1947, and the total value of the emerald sold from it, up to November 1951, was nearly half a million rupees. Other emerald occurrences have been found at Bubani, in Ajmer-Merwara, 2 miles from Gegal-Akhri, on the Delhi-Jaipur main line of the Western Railway, where conditions are much the same as those at Rajgarh, and from the Gamguda and Tekhi areas of Udaipur. The first prospect is between 15 and 16 miles from Nathdwara railway station, and the second about $2\frac{1}{2}$ miles south-east of Deogarh railway station.

Indian emeralds then occur in metamorphic talc-biotite schists near their contacts with pegmatites and other acidic intrusions, and the minerals associated with them are quartz, feldspar, tourmaline, apatite, actinolite, talc and biotite. A few stones have been recovered from detrital deposits shed from the parent rock, and they have not been found in the associated pegmatites themselves. They are said to occur mainly in the form of hexagonal crystals, or as angular grains and broken pieces, for they are generally very

brittle and easily crumbled. The crystals range from a fraction of an inch to almost five inches in length, but such large specimens are rare and most of them are marred by flaws, cracks and web-like inclusions, as well as by thin layers of biotite and talc. At the same time, pieces have been obtained upwards of a cubic inch in size, with 'complete transparency, dark green colour and very minor cracks and flaws'. The best stones have come from the Rajgarh deposits and have brought higher prices than those from Kalaguman, owing to their larger size, better colour, softer lustre, and clearer transparency.

At the mines, when a stone is found it is placed immediately into a locked box, the contents of which are finally emptied into a bag which is sealed under strict supervision. Later, in preparation for sale, any waste rock or associated minerals adhering to the emerald crystals are removed with the aid of suitable tools. The gems are then boiled in both alkaline and acidic solutions, and are by this means rendered sufficiently clean to exhibit their quality and the size of the finished stone that they are likely to yield. Finally, they are given a thin coating of oil, before being graded into the six quality classes and sorted into the various lots which are later offered for public auction in Jaipur. These auctions are held under the joint supervision of the Government and of the mine-owners. In the preparation of the notes on emerald mining we have been greatly assisted by the report of B. Bhargava.

We have been unable to obtain technical descriptions of the various grades into which the emeralds are divided, and no descriptions of them have been published, but Ajmer emeralds, presumably of the finest quality, have been examined by the American specialist, Dr A. E. Alexander, who states that they were for the most part quite clear and as far as colour was concerned rivalled the emeralds of Muzo origin. Again, of four specimens from Kalaguman, examined by Dr E. J. Gubelin, the eminent Swiss gemmologist, two were described as comparatively clear to the naked eye, vividly lustrous and of a rich green colour, similar to that of the finest gems from El Chivor. A third was a very beautiful stone with a soft, velvety lustre and a pronounced emerald-green colour, resembling a Muzo example, and a fourth was said to be lustrous with a warm yet vivid glow, and a soft, emerald-green colour in no way short of the finest Muzo quality. The interiors of the third and fourth specimens were thinly veiled by delicate *jardins*. H. Crookshank describes the colour of the Kalaguman stones (presumably of the first quality) as 'exquisite' and their 'water' as almost perfect, but he adds that in the opinion of expert jewellers they are not as clear as the best South American examples. Muzo and El Chivor are localities in the State of Colombia, in South America, from which the finest emeralds in the world have been derived since the sixteenth century.

It is not known what proportion the quantity of first-grade stones bears to the total amount of material found, but it is probably quite small, for Crookshank remarks that on the whole the quality of the Kalaguman stones is a little disappointing, the vast majority of them having been used for beads and ring-stones of a semi-precious type. Some London jewel merchants speak of Indian emeralds as being somewhat dark in colour and displaying rather shimmering inclusions, but to what grade in the Indian scale of classification these particular examples belonged we do not know. Moreover, necklets of emerald beads, supposed to be entirely of Indian origin, have been found to contain stones from both South Africa and Siberia. Gem specialists have little difficulty in distinguishing the provenance of any particular stone. R. Webster, to whose help we are indebted, has drawn attention to the typical, two-phase, comma-like, microscopic inclusions of Indian emeralds, a feature of diagnostic value, due to the presence in them of negative crystals filled with liquid and a gas bubble. For a full description of these and the other physical characters of Indian emeralds the writings of Webster, Alexander and Gubelin should be consulted.

CHRYSOBERYL

Chrysoberyl is an aluminate of beryllium, BeAl_2O_4 , which crystallizes in the orthorhombic system; colourless when pure, it often possesses various shades of yellow, brown and green. It is harder than topaz but not as hard as corundum, and when transparent or translucent makes an interesting gem stone.

Sulphur-yellow, platy crystals of chrysoberyl occur with deep blue apatite in the feldspar-corundum rocks of the Kangayam neighbourhood, Coimbatore district, Madras, and are said to be sent occasionally to the lapidaries in Ceylon. There are extensive ancient workings for chrysoberyl at Manikkal—a name which means 'gem quarry'—in the Nedumangad taluk of Travancore where illicit operations commenced again in 1942. Rumours of valuable finds led to a further influx of unlicensed miners and finally to official intervention in 1944. Preliminary prospecting on behalf of the State by the Travancore Rubber Works was inconclusive, and in 1947 E. K. Raghavan Pillai, of the Geological Department of Travancore, was deputed to undertake a systematic exploration of the whole area. He selected three unworked sites and from the first obtained 548 chrysoberyl fragments from the first 2 or 3 feet of the top soil, the majority of which were portions of yellow transparent crystals. These are locally known as *thala* and as they possess no chatoyancy are of but little value. About 35 of the specimens, however, ranged up to $2\frac{1}{2}$ carats in weight and though not entirely flawless had the true cat's eyes appearance and were worthy of the attention of the lapidary. In the case of the second site, of 293 specimens from between 3 and 4 feet below the

surface, not more than a dozen were of any value. The third site yielded about a pound of yellow transparent crystal fragments from 5 to 7 feet below ground level. The whole character of the occurrence as well as the erratic distribution of the gems lead to the conclusion that though chance finds may be profitable to the individual, as a commercial undertaking large-scale mining of these chrysoberyl deposits is unlikely to be profitable. Small crystals of a yellowish tint have been found, again in association with apatite, in a vein granite at Ramidi, Cuttack district, Orissa. Transparent yellow stones of good quality occur with beryl in mica-bearing pegmatites at Govindsagar, Kishangarh, Rajasthan. Pale, greenish yellow to amber, and yellowish brown, vitreous crystals were discovered accidentally in the debris of a beryl working at Lohagal, near Ajmer, about 1944, where they are associated in eluvial deposits with monazite and columbite-tantalite. It is probable that the stone is of commoner occurrence in the pegmatites of Rajasthan than is generally realized, for it is not of striking appearance in the rough state, and, resembling greenish quartz on casual inspection, may have been overlooked by the miners concerned. Chrysoberyl is regularly cut both in Mogok and in Ceylon. The Burmese stones vary from colourless specimens to bright, lustrous, sea-green, single crystals and to beautiful, transparent, wine-yellow and practically flawless trillings. Water-worn specimens from the gem gravels resemble the local peridots, though somewhat lighter in tint and considerably harder.

The Ceylonese stones include the true 'cat's eyes', the chatoyant, wavy, opalescent, greenish variety of silky lustre, not to be confused with the quartz 'cat's eyes', and the delightful alexandrite, 'one of the rarest and most beautiful of all gems,' unique in that it appears green by daylight and red in artificial light.

GARNET

The great family of garnets arrange themselves into an isomorphous series of cubic silicates, all of which possess the same general chemical constitution, and most of which yield gem stones of interest to the lapidary and jeweller. The names and composition of the chief members of the family, all of which occur in India, are as follows:

Almandine,	an iron-aluminium silicate,	$\text{Fe}_3\text{Al}_2(\text{SiO}_4)_3$
Pyrope,	a magnesium-aluminium	" , $\text{Mg}_3\text{Al}_2(\text{SiO}_4)_3$
Grossularite,	a calcium-aluminium	" , $\text{Ca}_3\text{Al}_2(\text{SiO}_4)_3$
Andradite,	a calcium-iron silicate	" , $\text{Ca}_3\text{Fe}_2(\text{SiO}_4)_3$
Spessartite,	a manganese-aluminium	" , $\text{Mn}_3\text{Al}_2(\text{SiO}_4)_3$
Uvarovite,	a chromium-calcium	" , $\text{Ca}_3\text{Cr}_2(\text{SiO}_4)_3$

These are theoretical, simple compositions, but in nature, one garnet can, and often does, contain an admixture of the constituents of another. It is a particularly common mineral in India, especially as macro-crystals in the ancient rocks both of the Peninsular and

extra-Peninsular areas, but localities of stones of gem grade are few and far between. The whole family is essentially dodecahedral or trapezohedral in habit, the crystals usually forming simple dodecahedra, sometimes with their edges bevelled off by another form.

Garnets were cut in India long before the Christian era and the country furnished stones to both Greek and Roman merchants. Jewels of garnet, topaz, carnelian and rock crystal were found in the stupa at Piprahva where remains of Gautama were interred about 483 B.C. 'The carbuncle of the ancients', wrote V. Ball, 'is garnet cut, as it is called, *en cabochon*. The art is still practised in India, and the stones, when of good quality and well cut, are very beautiful and would meet with more esteem were it not that they happen to be cheap, which has put them within the reach of so large a circle that they are made but little use of.'

Precious garnet is won in certain parts of Rajasthan, Jaipur, Udaipur, Kishangarh and Ajmer-Merwara. The 'real Jaipur garnets', extensively sold to tourists, probably come from various localities in Ajmer and Kishangarh. The stones are found in the soil covering hollows in the surface of Aravalli schists, especially where these are traversed by granitic intrusions; from shallow workings on the outcrops, and from the beds of the rivers draining these rocks. Mining appears to be carried on intermittently, and the returns may be blank for several years and then show the production of a few tons, which it doubtless takes the market a considerable time to absorb. Thus, 7.3 tons were reported from Jaipur in 1930 after a decade with no output at all. The finest stones come from the Sarwar district of Kishangarh. They are cut in Jaipur and Delhi and a portion of the cut stones still finds its way abroad to other countries. It is usually stated that most Rajasthan garnets belong to the almandine group, but the variation in their colour from deep red, through reddish purple, to purple seems to indicate some intermediate varieties in the series which begins with the blood-red pyrope and, by replacement of its magnesium content with iron, ends with the nearly pure, violet coloured almandine. A rhododendron-red variety, corresponding to a mixture of one unit of almandine and two of pyrope, has been termed rhodolite. Gem garnets of these types occur at various other localities, amongst them being Gharibpet, Kaketla and Palonka, in the Warangal district of Hyderabad. Large quantities of stones were at one time sent from Gharibpet to Madras for cutting, while a neighbouring area, Khammamet, furnished many parcels for export to Europe about 1925.

Hessonite, or Cinnamon Stone, a honey-brown variety of grossularite, has been reported from Mudapala, in Orissa, by B. C. Roy, and is also said to occur in the vicinity of the Seven Cairns Hill, on the Nilgiris, near Ootacamund, Madras. Yellow and cinnamon-coloured hessonites are the commonest varieties

in the gem gravels of Ceylon, and apparently most of the stones of these types used in jewellery come from the gravels of the Ratnapura and Balagonda districts of the island. The terms 'hyacinth' and 'jacinth', sometimes used for the orange, flame-coloured and reddish brown garnets of Ceylon, which also belong to the hessonite group, are incorrect and misleading and should be avoided. The yellowish brown to light yellow and yellowish white garnets from the Coimbatore district of Madras, as well as the green specimens from quartz veins traversing hornblende schists at Sankaridrug, in the Salem district, and others from unknown localities in Burma, are perhaps varieties of grossularite.

The town of Kondapalle, near Vijayawada (Bezwada), in the Krishna district of Andhra, was famed at one time for its polished garnets cut *en cabochon* as 'carbuncles'. The rough stones were probably derived from the khondalites, but Dr Krishnan states that very little suitable material is to be found hereabouts at the present day. There are old garnet workings in garnet amphibolites and mica schists near Ellamman Kovilpatti, a few miles south of Kulittalai, in the Tiruchirapalli (Trichinopoly) district, and evidences of similar activities near Sevitturangampatti and Toppur, in Salem. Good gem garnet is also said to be available near Melamattur, in the Tirunelveli (Tinnevely) district. Transparent garnets of purple and violet shades are present in the mica schists near Utukur and one or two other places in the mica belt of Nellore.

Though possessing no value as gem stones, the deep red to dark chocolate and black almandines of the Rajasthan mica belt may be mentioned, as they occasionally attain the size of a small football, while specimens as large as billiard balls are common. As crystals exhibiting combinations of dodecahedral and trapezohedral forms they are good collectors' examples. Excellent cinnamon-brown crystals of grossularite, which in addition to the forms mentioned also exhibit hexoctahedral faces, come from a pegmatite at Daolathgarh, in Mewar.

Uvarovite, the brilliant, emerald-green, chrome garnet occurs in dodecahedral crystals in chromite, near the Hanle monastery, Rupshu, Kashmir, though they are said to be too small to be of much utility. It is also found in the Jade Mines area of Myitkyina, Burma. Of spessartite, the manganese garnet, G. Herbert Smith writes as follows: 'If only spessartite of gem quality were found in sufficient quantity, its aurora-red colour would render it most acceptable for use in jewellery. Suitable spessartites are so rare as to be curiosities.' Spessartite is a fairly common mineral in Indian rocks of the Gondite Series and the best crystals come from Jothvad and Narukot, in Bombay; Bichua and Gaimukh, in Chhindwara, and Chargaon, Satak and Waregaon, in Madhya Pradesh. According to Sir Lewis Fermor, it is not often that the crystals are perfectly transparent and free from darkening, but when unchanged 'they are often of a most beautiful, bright orange

colour and if they could be obtained in quantity and of a fair size, they might be used as a most lovely gem'. Other darker shades are met with, orange-red—the tint of guava jelly—to blood-red. Spandite, a garnet intermediate in composition between spessartite and andradite, occurs in the Kodurite Series of the Srikakulam district of Andhra, and in particular at Garbham and Ramabhadrapuram. It varies in colour from deep orange to brown orange-red and blood-red and never displays the lighter orange shades of the true spessartite.

IOLITE

Iolite is the gem variety of the mineral cordierite, a complex silicate of aluminium and magnesium, $Mg_2Al_4Si_4O_{18}$, in which part of the magnesium may be replaced by ferrous iron and manganese and part of the aluminium by ferric iron: water may also be present. It may possess almost any shade of blue, crystallizes in the orthorhombic system, usually as short, prismatic, pseudo-hexagonal twins, and derives its name from the Greek word *ion* which means 'violet', in allusion to one of its colours. It has a synonym 'dichroite' on account of its strong bi-coloured character, visible to the naked eye without instrumental aid.

That iolite was a gem revered in Ancient India is indicated by the presence of several pieces amongst the relics excavated at Buddh Gaya about 1880, and believed then to be about 2,000 years old. Pale blue to indigo blue iolite, transparent to slightly cloudy, occurs in a few places in the Kadavur *zemindari* of the Tiruchirapalli district, Madras, in small lenses and streaky masses, associated with vein quartz and granite gneiss. About 2 miles west of Kiranur there are old pits formerly worked for iolite, pink corundum and garnet. The country rocks here are crystalline limestones and amphibolites with intrusive pegmatites and quartz veins. The mineral is also stated to occur in violet patches and spots in a vein granite near Thiruvella, in Travancore. Cordierite is abundant in certain sillimanite-biotite schists, associated with spinel and sapphirine-bearing rocks of the Madugula taluk of the Visakhapatnam district of Andhra. Though not of gem quality, the occurrence is important as an indication of the formation of cordierite as a product of the intermixing and metamorphism of an ultrabasic suite of rocks with the khondalites of the Eastern Ghats, and as a guide in future searches for better grade material.

Iolite is found as small rolled pebbles in the gem gravels of Mogok, though it is not common there. Cut in the right direction these make attractive, pale, smoky violet stones, which, though they may lack both 'fire' and brilliance, nevertheless possess an alluring charm of their own: their comparative rarity probably accounts for the little use that is made of them. The term 'water sapphire' by which they are known, especially amongst gem traders in Ceylon,

though even there the stone is rare, is deceptive and should not be used.

KYANITE

According to Max Bauer, one of the greatest authorities on precious stones in his day, the best crystals of gem kyanite are said to come from unknown localities in India, a country in which it is more extensively used than elsewhere. 'There is no doubt', wrote Bauer, 'that kyanite is obtainable at many places in India, but it has been suggested that the stones worn in that country have all come from Europe.' This suggestion is incorrect, for kyanite is common enough in some of the Archaean rocks of India, and has been found in the Himalayas, the Punjab, Hyderabad, Andhra, Madras and Bihar.

Kyanite is a silicate of aluminium with the composition Al_2SiO_5 , a formula which it shares with andalusite and sillimanite, and both the first and last named minerals in their coarse and massive forms are worked on a large scale as refractories. Kyanite crystallizes in the triclinic system, usually in long thin blades, sometimes attaining a length of over 12 inches. As its name indicates, it is blue in colour and it has the extraordinary property of possessing two different degrees of directional hardness, so that it can be scratched by a knife on some faces but not on others. For this reason it is sometimes known as 'disthene'.

Kyanite is abundant in the schists and granites about Kanaur and Bhabeh and in many parts of Bashahr in the western Himalayas, where its beautiful blue colour has often led to its being mistaken for sapphire. When quite transparent, which is unhappily not often the case, it makes a very pretty gem stone when properly cut, varying from a pale sky-blue to a deep cornflower shade. It is used by the lapidaries in Patiala, their material being derived from bluish, thin-bladed, as well as short and thick crystals, found, usually in association with calcite, in the hills just west of Narnaul, the chief town of the district of the same name in Patiala. Deep blue kyanite has been described from the Badia region of the Dhalbhum subdivision of Singhbhum, and at Kanjikovil, $2\frac{1}{2}$ miles from Sittodu, in the Coimbatore district of Madras, there are old pits presumably made in search of gem kyanite though their debris today only contains grey and bluish grey material. Blue, bladed crystals are said to occur near Saidapuram and near Chundi, both localities being in the Nellore district of Andhra. Kyanite has the same composition as sillimanite, which under the synonym 'fibrolite' forms one of the rarer gem stones of Mogok and of Ceylon.

PERIDOT

Peridot is the clear green or yellowish variety of olivine which is sometimes referred to as chrysolite. Olivine itself, and its name is

sufficient indication of its colour, is an essential constituent of many basic and ultrabasic igneous rocks, and a member, in an intermediate position, of an isomorphous series of orthorhombic minerals, the end members of which are the magnesian silicate, forsterite, Mg_2SiO_4 , and the iron silicate, fayalite, Fe_2SiO_4 . One part of iron to about eight or nine parts of magnesium results in the green peridot, $(\text{Mg}, \text{Fe})_2\text{SiO}_4$. As olivine is unusually liable to alteration and decay, generally into serpentine, it is very rarely found in a fresh enough condition, or transparent enough, to be cut into gem stones.

According to Max Bauer, 'the source of the chrysolite which is used in the trade for cutting as gems is somewhat obscure, and both Pegu and the country of the Burmese are mentioned as localities for chrysolite, but the occurrence of the stone in gem-quality here or in India, is by no means well authenticated'. The greater portion of the world's supply of peridot has for many centuries been derived from the Island of Zerbirged (St John), in the Red Sea, where deep yellowish-green stones occur in veins of serpentized peridotite. The gem has not been reported from India or Pakistan, but it occurs in some quantity in the gem gravels of the Bernardmyo valley, some ten miles north of Mogok, Burma. As it is a comparatively soft stone, being somewhat softer than quartz, and as the pieces when recovered are only slightly rounded and still show their crystal outlines, it is evident that they have not travelled far. They are in fact derived from the peridotites of the Bernardmyo area, of which three main exposures are known. They are medium to coarse-grained, holocrystalline rocks consisting essentially of olivine with a subordinate quantity of pyroxene and occasionally a few grains of iron ore. Peridots have actually been mined from the decomposed outcrop of one of these bands which cuts across the mountain known as Mya Taung and runs northwards towards Pyaunggyaung. Burmese peridots vary from shades of yellowish green to olive green, and large gems are cut from them in the 'step' style for the pendants of necklaces. When such stones are viewed through the table facet, they display an apparent doubling of the opposite edges owing to the high double refraction of the mineral.

CHAPTER XVI

UNCOMMON GEM STONES

BESIDES the well-known precious stones already described, there are a number of other minerals which when found transparent or translucent enough, and of a sufficient size, can be cut into gems distinguished by a beauty of their own, though they may not commonly be found in the jewellery trade. Others, again, have little to recommend them beyond their rarity and are unlikely to be seen outside the cabinets of gem collectors or the show cases of museums. A number of Indian minerals which have been, or might be, used for such purposes are briefly described below.

ANDALUSITE

Andalusite, the orthorhombic silicate of aluminium, Al_2SiO_5 , is a sister mineral of kyanite and sillimanite (fibrolite), which have the same chemical composition and both of which are found in gem varieties. It occurs in nearly square prisms, has a vitreous lustre, a hardness between that of quartz and topaz and a wide variety of colours, including greys, browns, greens and red or pink. Its dichroism is perhaps its most remarkable property. Water-worn pebbles of greenish shades from the gem gravels of Ceylon are cut and sold in Kandy as alexandrite, the rare and beautiful variety of chrysoberyl, but they lack its capability to change its colour in artificial light. Opaque kinds of the mineral are common enough in some parts of India. Rectangular prisms, up to four inches in length, can be obtained in quantity at Raisindri Pahar, in north Singbhum, but they are full of opaque inclusions. Along the southern slopes of the Bhiaura Hills, in north Hazaribagh, there are places where the local clay schists are so full of small crystals that their weathered surfaces are covered with an andalusite gravel. The schists and slates of the Mandan Group of rocks at Madan Barod, Tasing and Mandaor, in north-west Alwar, Rajasthan, abound in crystals of andalusite and staurolite. Dudhi, in south Mirzapur, is another locality where 'rather fine crystals of andalusite' have been found.

APATITE

Apatite is a phosphate of calcium in which both chlorine and fluorine are usually present. It crystallizes in the hexagonal

system, generally as prisms capped by pyramidal faces and, as far as its gem varieties are concerned, it may be blue, violet, green or yellow in colour. It suffers from the fault of softness, is not particularly durable as a cut stone for this reason, and consequently is made little use of in jewellery, as it only occupies the fifth position between fluorite and orthoclase feldspar on the standard scale of hardness.

A remarkable, deep sea-green variety has been found at Devada, Srikakulam district, Andhra Desa; while at Kodur, in the same district, beautiful, pale blue, rounded prisms up to $\frac{1}{4}$ inch in length were obtainable. A lavender-coloured though much flawed kind also came from the same place. Dull sea-green to olive-green apatite occurs very frequently in the pegmatites of Rajasthan, where it is often mistaken for beryl, and though sometimes cut as a gem is really too soft for the purpose. An attractive blue variety is found as rounded pebbles in the gem gravels of Mogok, Burma, where it is cut and sold mainly as faceted stones for necklaces. The dichroism of apatite is feeble as a general rule, but the Burmese variety is exceptional in the twin colours blue and yellow. According to Webster these stones also show an absorption spectrum consisting of fine lines in the green and blue regions which are attributed to rare earth elements.

The uses of the commoner varieties of apatite are described under PHOSPHATES.

AXINITE

Many years ago a firm of jewellers in Calcutta submitted a specimen to the Geological Survey for determination which had been sent to them from Kashmir, where they believed it was obtainable in considerable quantities. It proved to be purple-brown axinite, in both granular and crystallized form, but no further information regarding its locality was ever obtained.

Axinite is a hydrated borosilicate of aluminium, with varying amounts of calcium, manganese and ferrous iron, crystallizing in the triclinic system, often in flat, well-developed forms with the axe-like edges to which it owes its name. It is about as hard as quartz, possesses a wide colour range including pearly grey, pale pink, dark honey-yellow, clove-brown and plum-blue, is transparent to translucent and strongly dichroic, a property which adds to its appearance after cutting.

Axinite was discovered by Griesbach, 7 miles west of Kandahar, and about $1\frac{1}{2}$ miles south-east of Kokoran, in Afghanistan, where it occurs with calcite in veins traversing hippuritic limestone, which has been greatly altered by basic and syenitic intrusions. Most of Griesbach's specimens were looted and only one reached Calcutta. It is crystalline-massive, with small indistinct crystals and very pale pink to pinkish white in colour.

DANBURITE

Danburite is a borosilicate of calcium, $\text{CaB}_2(\text{SiO}_4)_2$, which crystallizes in the orthorhombic system in prismatic forms greatly resembling some of those assumed by topaz. It varies from colourless to pale yellow shades, and is found at Mogok in the gem-bearing gravels as water-worn crystals which are very liable to be mistaken for topaz. It does not possess the highly perfect cleavage of the latter however, and its specific gravity is somewhat lower, so that danburite will float on methylene iodide while topaz will sink. Originally discovered at Danbury, Connecticut, U.S.A., most of the yellow danburite, according to Webster, now comes from Burma and Madagascar.

Though it is outclassed as a gem stone by its more attractive sister, it has furnished some remarkable examples. One magnificent stone, which was found at Mogok, is now in the British Museum. Mr G. Herbert Smith describes it as 'step-cut, perfectly transparent, flawless, and an attractive wine-yellow shade of colour, it weighs 138.61 carats, and measures $1\frac{1}{2}$ by 1 inches in the girdle section and $\frac{3}{8}$ inch in thickness'.

DIOPSIDE

Diopside is a member of the group of monoclinic pyroxenes, prismatic in habit and a silicate of calcium and magnesium, $\text{CaMg}(\text{SiO}_3)_2$, usually with some ferrous oxide replacing magnesia and to which it owes its green colour. When this is well developed in transparent crystals they are sometimes cut as gems. The fine green specimens from Mogok, which are often chatoyant and produce 'cat's eyes', also contain a small percentage of chromium. Diopside is prevalent in the calc-gneisses of the Stone Tract, but it is also present in certain coarse-grained contact rocks, where the limestone bands of the region have been intruded by veins of feldspar-rock and of granite-pegmatite: from sources such as these the material in the gem-gravels may have been derived.

A pale to leek-green variety of diopside, known as malacolite, has sometimes been cut for use in jewellery, and the bands of irregular crystals which occur in the hornblende schists of the Kolar goldfield are worth further examination from this point of view. This also applies to the green crystals of coccolite (a closely related mineral) which crowd a crystalline limestone, 6 miles north of Vizianagram, and to the green diopside, found with yellowish-red garnets in a similar rock, 2 miles north-west of Purshottampur, Ganjam district, Orissa. Although diopside and its varieties are widely distributed in India as the products of the metamorphism of dolomitic limestones and dolomites, it is unlikely that material of gem quality is anything but very rare.

Before it had been fully investigated, the manganese-bearing, monoclinic pyroxene blanfordite was believed to resemble violane,

a violet-blue variety of diopside from Piedmont, Italy. Blanfordite has been found in manganese ore deposits at Ramdongri and Kacharwahi, Nagpur district, Madhya Pradesh, and at Jothvad, Narukot, Bombay. It is deep crimson in colour with a very striking pleochroism in carmine, lilac and deep blue shades. Crystals up to two inches in length have been found, but unfortunately it is often altered to an unpleasant chocolate-brown.

The massive, diopside rock of Idar, unique in India, and probably very rare elsewhere, is described under DECORATIVE STONES.

ENSTATITE

Enstatite is an orthorhombic pyroxene composed of magnesium silicate, MgSiO_3 , and with little or no iron it is white to greenish white in colour. As the iron content increases, the green colour becomes more pronounced and various physical contents such as specific gravity and refractive indices increase. When the proportion of the iron silicate, FeSiO_3 , is greater than 15 per cent, enstatite passes over into hypersthene with a marked colour change to nearly opaque, dark greens, dark browns and almost black. Bronzite is an iron-bearing variety of enstatite, greyish green to olive-green and brown in colour, though the bronzy lustre which it sometimes possesses is not an essential feature. Schillerization due to the presence of minute scales of iron oxide, or of brookite (titanium dioxide, TiO_2), is very characteristic of hypersthene and is the reason why it is sometimes cut *en cabochon*, when such inclusions impart an iridescent or spangled appearance to the otherwise dark surface of the stone.

The minerals are common primary constituents of various intermediate, basic and ultrabasic rocks and in certain members of the charnockite group, but gem varieties of any of them are very rare. The first enstatite gems are stated to have come from South Africa, where they accompany the diamond in the 'blue ground' of the Kimberley mine. They are described by G. Herbert Smith as 'beautiful in colour but seldom exceeding two carats in weight and consequently seldom enter the market'; he adds that larger pieces, though inferior in colour, have been produced at Mogok, Burma. To this we may add that the norites of the Stone Tract contain hypersthene and resemble the corresponding member of the charnockite series of southern India. In the rocks north of Chaunggyi Konsan, again, the pyroxene belongs to the enstatite-hypersthene series, corresponding to the pyroxenites of the charnockite series.

Specimen stones of the altered enstatite, known as bastite, leek-green in colour, and analagous to serpentine in composition, are also said to have been found in Burma, and they too probably come from Mogok.

EPIDOTE

Epidote is the best known member of a family of complex, basic orthosilicates which also includes zoisite, thulite, piedmontite and allanite. They are all similar in atomic structure and related in chemical constitution. Zoisite is a basic silicate of calcium and aluminium, $\text{Ca}_2\text{Al}_2(\text{SiO}_4)_2(\text{OH})$, which by replacement of part of the aluminium by iron passes into epidote, $\text{Ca}_2(\text{Al}, \text{Fe})_2(\text{SiO}_4)_2(\text{OH})$; with manganese as well as iron taking part the manganiferous epidote, piedmontite, is formed, while in allanite the rare earth elements are also present. Zoisite, thulite and piedmontite are described under DECORATIVE STONES.

Epidote itself crystallizes in the monoclinic system, in prisms elongated along its axis of symmetry. It has a vitreous lustre and a perfect basal cleavage; though it may be yellowish to blackish green it generally possesses the unusual green of the pistachio nut, a unique colour in the mineral kingdom and one responsible for its alternative name 'pistacite'. This is not a popular shade and is said by Webster to preclude its use as a gem stone beyond the wants of collectors. Holden and Kraus, however, while admitting that pistacite does not have a wide appeal, state that it is not uncommonly cut in America. Transparent stones are often strongly dichroic, appearing dark green in one direction and brown in a direction at right angles. It is harder than orthoclase feldspar and rather softer than quartz.

It is remarkable that amongst the many recorded occurrences of epidote in India, where the mineral is common in many kinds of Archaean rocks, fine crystals of gem quality do not appear to have been found. Stoliczka writes of short prisms of yellowish and bright green colours in an epidote rock of the Puga valley, Rupshu, Kashmir, and Sir Lewis Fermor of beautiful, bright green prisms noticeable in a calciphyre at Bichua, Chhindwara, Madhya Pradesh, but such short descriptions are not sufficient. The locality of the brownish, yellowish-green, translucent or nearly transparent crystals, supposed to occur with corundum, somewhere in Madras or Andhra, is not known.

A pistachio-green to dark yellowish-green epidote is sometimes found in water-worn pieces transparent enough to be cut into gem stones at Mogok, though its perfect cleavage renders it liable to flaws. The chromium-bearing epidote, tawmawite, described by its discoverer, A. W. G. Bleeker, as 'a new and distinct member of the epidote group', comes from the vicinity of Tawmaw, the jadeite-mining centre in the Myitkyina district, Burma. The French authority, Lacroix, prefers to regard it as chromojadeite, but Dr H. L. Chhibber, with a wide experience of the area, states that 'tawmawite occurs in the contact rocks at a number of different localities, usually associated with the chrome-garnet, uvarovite. This chromiferous epidote has only been found in a massive state, hard and compact and of a beautiful dark green colour. Its index

of refraction, cleavage, hardness, specific gravity and chemical composition prove that it really is an epidote. It has a very strong pleochroism in emerald-green and bright yellow colours'.

A handsome gneissose rock containing large flesh-coloured crystals of orthoclase feldspar and yellowish green epidote, known as unakite, comes from Singhbhum, and J. A. Dunn has listed various places in Ranchi district, Bihar where 'beautifully tinted yellow-green epidotes' could be obtained for ornamental purposes. Red aplites, streaked with pistachio-green epidote, occur north of Beawar, in Ajmer-Merwara, and about Desuri and Bijapur, in Jodhpur, Rajasthan. Pistacite-quartz schists, highly charged with epidote, sometimes with the mineral irregularly scattered through them after the fashion of garnets in a garnetiferous schist, occur between Dasur and Tumoy, in Nellore, Andhra. Near Pind, in Mewar, Rajasthan, the chilled edge of a dolerite dyke is associated with a vein of yellowish green epidote, quartz and reddish idocrase. In the Bellary district of Mysore, pistacite is the most remarkable accessory mineral in the finer-grained gneisses of some localities. 'Where the rock is much weathered, as it often is,' writes R. B. Foote, 'the country is thickly strewn with fragments showing brilliantly yellow-green pistacite, contrasting in a very pleasing way with the red or bright-pink feldspar.' Indian geological literature contains many more examples of these and other types of occurrence of epidote.

EUCLASE

This rare silicate of aluminium and beryllium, $\text{Be}(\text{AlOH})\text{SiO}_4$, occurs in the form of prismatic crystals belonging to the monoclinic system. They have the same hardness as beryl and much the same pale green and blue colours as its variety, aquamarine. They differ, however, in the possession of a perfect cleavage, parallel to the plane of symmetry, which makes them difficult to cut, and to which they owe their name, from two Greek words meaning 'easily breaking'. Regarding euclase, G. Herbert Smith writes: 'The lovely crystals in which it has been found are coveted for mineral collections and are worth more than the stones which might be cut from them. Its crystals are most attractive to the eye, with their elegant prismatic shape and numerous smooth faces.'

The principal source of euclase is the Ouro Preto region, in the State of Minas Geraes, Brazil, where it is associated with yellow topaz in chlorite schist. Euclase of a pale green colour occurs with black tourmaline, kyanite, minute red garnets and crystals of corundum or sapphire, in very coarse-grained pegmatites which traverse schistose gneisses in the vicinity of the sapphire mines of Sumjam, in Kashmir, but no descriptions of the mineral itself have been published.

FIBROLITE

The name 'fibrolite' was given originally to the mineral now known as 'sillimanite', the orthorhombic silicate of aluminium, Al_2SiO_5 , a chemical composition which equally applies to kyanite and andalusite. Although it is a mineral of wide distribution and one which is won on a large scale in India for refractory purposes, clear, independent crystals of appreciable size are very rare, and its use as a faceted gem was not recognized before 1920, though both in Burma and Ceylon it had probably been cut long before this date and confused with iolite (cordierite).

It was first identified in the British Museum together with eighteen rough stones, sent there from the washings of a ruby mine on a hill-side near Mogok. The worked stone was a perfectly clear specimen, a little over 4 carats in weight, transparent, flawless and of a pale sapphire-blue colour somewhat resembling iolite. The rough stones had the forms of rhombic prisms, considerably rounded, and when still more water-worn, of elongated pebbles. They were from 1 to $1\frac{1}{2}$ cm. long by $\frac{1}{2}$ to $\frac{3}{4}$ cm. across, and on most of them the highly perfect pinacoidal cleavage was a prominent feature. In their original matrix they had evidently been perfectly developed crystals. They were clear and transparent and of a pale sapphire-blue, ranging in some specimens to almost colourless. Strongly pleochroic, the maximum colour was seen when the crystals were viewed across the prism zone; along the vertical axis they were colourless. Their hardness was $7\frac{1}{2}$, higher than that usually given in textbooks, and a sharp corner readily scratched the face of a quartz crystal. Gem fibrolite of much the same habit occurs in the gem gravels of Ceylon, though there the rough crystals tend to be etched and corroded. In addition to the pale blue, strongly pleochroic types characteristic of Burma, Ceylon also yields pale, greenish-grey stones, some of which, full of fine, straight lines, become translucent with a high degree of chatoyancy. They are, in fact, fibrolite cat's eyes and closely resemble cymophane (a variety of chrysoberyl) in appearance. The same optical effect is sometimes produced by the aggregation of the fibrous crystals themselves. In this note we have drawn freely on Dr L. J. Spencer's descriptions of the stones, and his paper must be consulted for further details of their physical constants.

In both Burma and Ceylon, gem fibrolite is probably derived from the sillimanite-bearing rocks of the Khondalite Series, and their near identity with the Khondalite Series of the Visakhapatnam district of Andhra raises the question of the possibility of the occurrence of gem fibrolite in that region too.

HAMBERGITE

In 1912, the late R. C. Burton found a single crystal of this rare borate of beryllium, $\text{Be}_2(\text{OH})\text{BO}_3$, together with cookeite

(a micaceous silicate of lithium and aluminium), green and brown tourmaline, beryl, euclase, amblygonite and prehnite, in concentrates from pits in the granite debris of the Kashmir sapphire mines, which had been given to the Geological Survey in Calcutta. There can be no doubt that these minerals came from the local granite pegmatites. Hambergite had already been described by Brogger from a pegmatite of alkali syenite in southern Norway, and by Lacroix from pegmatites in central Madagascar, and the common resemblance in the three modes of occurrence is apparent. The use of the mineral as a gem stone is said to have been unknown until the large, colourless crystals were found in Madagascar.

Hambergite crystallizes in the orthorhombic system as narrow, striated prisms, capped with smaller, pyramidal faces, has a brilliant lustre and comes between quartz and topaz in the scale of hardness. It is colourless, transparent and clear, with a density of only 2.36; beyond its rarity it has no particular recommendations as a gem, though it possesses a large double refraction only exceeded by those of sphene and cassiterite amongst minerals which have been cut as precious stones.

LAZULITE

This deep blue, minor gem stone was first recognized in India in a collection of minerals sent to the Geological Survey in 1883, by the then Resident in Kashmir. La Touche was given a few more specimens of a dark blue colour while at the sapphire mines in 1887, and they apparently came from a very inaccessible location two or three days' journey from Gulabgarh, in Kishtwar.

Lazulite is a translucent, azure-blue, basic phosphate of magnesium and aluminium, $MgAl_2(OH)_2(PO_4)_2$, in which varying amounts of ferrous iron may replace the magnesium. It should not be confused with lazurite (lapis lazuli) with which it has nothing in common except its intense blue colour. It crystallizes in the monoclinic system, usually in acutely pyramidal forms, which display a deep blue colour when viewed along one axis and a pale greenish blue along another. It is somewhat brittle and rather softer than orthoclase feldspar, and as far as India is concerned has only been obtained in compact massive and granular forms up to the present time.

On Bhamasur Hill, in the Bhandara district of Madhya Pradesh, there is a schistose quartzite with bright blue streaks and bands and abundant crystals of whitish, light greenish and greenish blue colours. The blue constituent was originally and provisionally regarded by Sir Lewis Fermor as sapphirine, a translucent, deep blue silicate of magnesium and aluminium, which occurs as grains in certain rocks of the Visakhapatnam Hill Tracts of Andhra, but it was later proved to be lazulite by W. A. K. Christie, Chemist to the Geological Survey at the time. The accompanying accessory

mineral, which Fermor thought might be enstatite, proved to be either kyanite or clinozoisite.

PHENACITE

Phenacite, the hexagonal silicate of beryllium, Be_2SiO_4 , well deserves its name, which is derived from the Greek and means 'a deceiver', for it is quite easily mistaken for rock crystal. It is, however, somewhat harder than quartz and has a higher mean refractive index and double refraction, but its dispersive power is poor and it possesses little fire.

It is one of the rarer gem minerals of the Mogok Stone Tract where it has occasionally been cut into rather large, faceted, colourless, somewhat brilliant, lustrous stones with a distant resemblance to the diamond. Phenacite also occurs as very minute crystals in the gangue of the cassiterite-wolfram lodes of Mawchi, in Karenni, Burma; but this is not surprising as beryl is abundant there in some parts of the mine, and locally constitutes the greater part of the lode material, usually as coarse, crystalline aggregates of the typical pale blue shades.

RUTILE

Rutile, one of the natural forms of the dioxide of titanium, TiO_2 , is widely distributed as an accessory mineral in many of the crystalline rocks, but such occurrences are of no interest to the lapidary. Its crystals belong to the tetragonal system and its common habit is prismatic with pyramidal terminations; frequently found in geniculate twins, it is translucent to opaque with a metallic to adamantine lustre, a fairly good prismatic cleavage, a hardness between that of orthoclase and quartz, and of red and reddish brown to black colours, though green and yellow varieties are also known. Its refractive indices are very high, and it has the remarkable double refraction of 0.287, that of Iceland Spar (calcite), which is usually taken as an example, being 0.172. Rutile is also exceptional in having 'the phenomenal dispersion ("fire") of approximately 0.3, over six times as great as that of the diamond'. (R. Webster). Yet the mineral has only very occasionally been used as a gem stone, the green variety being the one most favoured for the purpose.

P. N. Bose found rutile in large pieces, but of undescribed quality, near Ghatasher, Narnaul district, Patiala, and S. K. Chatterjee noticed brick-red crystals in schorl rocks at Mogra and Pohra, in Bhandara, Madhya Pradesh. Hackett described thin quartz veins carrying white feldspar and rutile, intersecting quartzites in the Motidongri ridge, a short distance south of Alwar, Rajasthan. J. A. Dunn states that rutile is common in the mica schists of Lapsa Buru, Kharsawan, Singhbhum, and that crystals

up to two inches in length may be obtained on the south-west side of the South Hill there. Scattered crystals may also be found close to the kyanite deposits near Salbani, in Manbhum. In the absence of fuller descriptions it cannot be stated that any of these occurrences will furnish material of gem grade, but the reddish brown, rolled pebbles of rutile from Mohynin, in the Katha district of Burma, are probably suitable for cutting. Rutile is now made synthetically, by the same methods used in the production of artificial corundum and spinel, and cut stones with the same remarkable physical constants are available on the market in a wide range of colours.

Rock crystal, smoky quartz and amethyst sometimes contain fine fibres of rutile in thin, acicular, hair-like crystals and are cut and polished for ornamental purposes. Excellent examples of the clear and smoky varieties come from unknown localities in Kashmir.

Granular rutile occurs in the beach sands of Travancore and is recovered on a large scale together with ilmenite (see TITANIUM).

SCAPOLITE

Amongst the miscellaneous stones displayed in the gem bazaar at Mogok, there used to be, and probably still are, *cabochon* cut 'moonstones' with an unusual but unmistakable blush of pale pink. These were first recognized as scapolites about 1913 and in later years supplies have become available from both Brazil and Madagascar.

Scapolite is of varied composition, as the name is loosely used to designate all or any of the intermediate members of an isomorphous series of minerals, varying in composition between marialite, $3(\text{NaAlSi}_3\text{O}_8) \cdot \text{NaCl}$ and meionite $3(\text{CaAl}_2\text{Si}_2\text{O}_8) \cdot \text{CaCO}_3$. They all crystallize in the tetragonal system, generally as transparent to nearly opaque prisms terminated by pyramidal faces with a vitreous to pearly lustre and two distinct cleavages parallel to prismatic faces. In colour they are usually white but may assume faint shades of red, yellow, green or blue.

The Burmese stones are found as rough crystals and water-worn pebbles in the gem gravels, and when cut *en cabochon* yield white, yellow, pink and violet-blue colours which are often chatoyant and provide cat's eyes of considerable attractiveness. This effect is said to be due to the inclusion of microscopic rod-like cavities. Their hardness is about equal to that of orthoclase feldspar. Their refractive indices are moderate and their birefringence weak. Anderson and Payne have shown that violet scapolite cat's eyes from Burma are strongly dichroic, in dark blue and pale lavender tints, and that they possess an indistinct absorption spectrum of chromium. The constants of these stones agree with those of a scapolite of intermediate composition to which the name dipyre has been given.

The exact source of these gem scapolites is not definitely known, but the calc-granulites around Mogok are scapolite-bearing; pyroxene-scapolite gneisses also occur, especially about Bernardmyo, while at Myo Taung, much nearer Mogok itself, scapolite is developed at the contacts of pegmatites and crystalline limestones.

SPHENE

Sphene, sometimes known as titanite, is a silicate and titanate of calcium, CaTiSiO_6 , which derives its name from the wedge-shaped habit of its monoclinic crystals (Greek: *sphen*, a wedge). Its transparent varieties in brown, reddish brown, yellow and greenish colours form gems of splendid appearance when cut, for it has outstanding optical properties. It owes its adamantine lustre to a high refractive index; and its 'fire', which is greater than that of the diamond, to its strong dispersion. It is also markedly dichroic in contrasting tints of yellowish green, reddish yellow and colourless, corresponding to its three principal optical directions. But it has one great defect, for its hardness is only about 5 on the standard scale and, as in the case of apatite, this is too low for a cut stone to preserve its edges or its polished surface under ordinary conditions of wear and tear.

The small crystals of sphene which occur sparingly as constituents of many igneous rocks are of no interest to the gemmologist; large ones are said to be found in gneisses, chloritic schists and crystalline limestones. Large and beautiful crystals, of a variety containing a noticeable percentage of the cerium earths, come from an unknown locality in Rajasthan. Greenovite, the manganese-bearing sphene, occurs in dark brown prisms, up to nearly $\frac{1}{4}$ inch in length, with spessartite and blanfordite, in a vein of pink feldspar at Jothvad, Narukot, Bombay. These crystals are transparent and pleochroic in shades of yellow-green and a pale, warm brown, the two colours being of equal strength.

STAUROLITE

Staurolite is a complex silicate of ferrous iron and aluminium, the formula of which may be $2(\text{Al}_2\text{SiO}_5)\cdot\text{Fe}(\text{OH})_2$, though part of the iron is often replaced by magnesium. Some mineralogists regard it as a near relative of the rare gem stone kornerupine, known in Ceylon and probably still to be found in southern India.¹

It forms prismatic, reddish brown, yellowish and brownish black crystals, often in cruciform, interpenetration twins, set approximately either at right angles or at an angle of about sixty degrees, to which it owes its name (Greek: *stauros*, a cross). It has

¹ Bright green kornerupine of gem quality was reported from Mogok, Burma, in December 1954, by C. J. Payne (*The Gemmologist*, XXIII, pp. 215-19).

a resinous to vitreous lustre when pure (which is very rarely the case), a poor cleavage and a hardness between that of quartz and topaz. Its mean refractive index is fairly high and its pleochroism very distinct red and yellow to green, but the colours change somewhat with the composition.

Common staurolite is very prevalent in certain crystalline schists of Rajasthan, Singhbhum, north Nellore and elsewhere and many examples of its abundance could be quoted, but it can only be used as a gem stone when sufficiently clear and then, after suitable cutting, its pleochroism, visible in ordinary light, is said to be very striking. It may be that the pale straw-coloured crystals of Ghagidih Hill, in Dhalbhum, or the deep red ones, described by B. C. Gupta as occurring in the central belt of the Aravalli System of central Mewar, Rajasthan, contain some suitable material. The cruciform twins are sometimes polished and worn as amulets and sacerdotal ornaments but they are of little value.

CHAPTER XVII

SEMI-PRECIOUS AND DECORATIVE STONES

CHALCEDONIC QUARTZ

AGATE and carnelian, with their numerous relatives, are forms of chalcedony, the translucent mixture of cryptocrystalline silica and amorphous hydrated silica (opal). Beads of beautiful workmanship, dating from the third millennium B.C., have been found on a number of prehistoric sites in the Punjab, Sind and Baluchistan, fashioned from agate and agate-jasper, carnelian and onyx, blood-stone and green chalcedony. Multiple strings of such beads were used in a great variety of patterns as necklaces and girdles by the ladies of Harappa, Mohenjodaro and other contemporaneous cities and towns. At Chanhudaro, a bead-maker's workshop has been excavated revealing the technique employed in those far-off times to shape, bore, polish and etch the long barrel-shaped, tubular and biconical beads of carnelian and similar stones. These finds antedate by more than 2,000 years the reference of Ctesias (the Greek physician at the Persian court of Artaxerxes II, who succeeded to the throne in 404 B.C. and died in 358 B.C.) to India as the source of the stones, or again that of Herodotus (c. 485-25 B.C.) to the fact that the Romans obtained sard and onyx from India for their finger rings. In later times still both Pliny (A.D. 23-79) and Ptolemy (A.D. 90-168) mention localities whence the Indian stones were derived. Cups of Indian onyx and carnelian were famed amongst both Greeks and Romans; indeed her semi-precious chalcedony, exported since the earliest times, has spread across the world to an extent which is not generally realized.

The main original sources of the stones are the amygdaloidal lava flows of the Deccan and Rajmahal Traps. In some parts of the Deccan, the surface is strewn with their geodes and nodules left after the weathering away of their enclosing rock, and in certain localities extensive beds of gravel and conglomerate of Tertiary and sub-Recent ages exist, made up almost entirely of water-worn pebbles of agate and chalcedony. Collected from such deposits or from river beds draining them, the stones reach the lapidaries in such centres as Jabalpur, Banda and elsewhere.

Until the beginning of the seventeenth century Limodra, in Rajpipla, was the principal centre of agate cutting in western India, but subsequently it was superseded by Cambay, in Gujerat,

until about 1918 when the industry became moribund. Although other regions contributed their own special varieties of stones to its craftsmen, the bulk of the material reaching Cambay came from Ratanpur and other places in Rajpipla, some 70 miles to the south-east. The date of the commencement of agate mining hereabouts is not known but the first authentic records, according to P. N. Bose, date from the end of the fifteenth or the beginning of the sixteenth century when an Abyssinian named Bawaghor, whose memory is still honoured by shrines in Limodra and Cambay, established a workshop at Limodra, within four miles of the nearest agate mines. At the same time the ruins of Limodra testify to its having been a town of some importance as early as the commencement of the eleventh century. Thus the workings must have been in existence long before they were referred to by the early European travellers including Varthema (between 1503 and 1508) and Barbosa (about 1514).

The Cambay agate trade did not escape the attention of the astute French jeweller Tavernier in 1651, while Hamilton in 1727 listed the various products of the Cambay lapidaries. From that time onwards many accounts have appeared, the most important being J. M. Campbell's 'Account of the Rajpipla Cornelians', published in 1880.

From the combined work of three officers of the Geological Survey of India, W. T. Blanford (1867), P. N. Bose (1908) and M. R. Sahni (1948), it is now known that the stones, locally known as *akik*, occur in gravels and conglomerates which are probably of Miocene age, that they were obtained by sinking temporary pits 25 to 60 feet in depth, and that these were located mainly in the Ratanpur-Damlai-Dholakva area, approximately 2 to 5 miles east and south-east of Limodra. It is to be noted that only the ferruginous portions of the conglomerate yielded stones of value, and that good specimens can still be collected in the fields and river beds and on the hill slopes over the further extensions of the same Tertiary rocks.

As the stones came from the pits they were dull objects, milky white or grey, brown to buff or yellowish in colour; after a preliminary chipping to remove their outward skins, to eliminate worthless specimens and to separate the more valuable onyx, cat's eyes and the yellowish, pellucid citrine, the remainder, now normally one to three inches in diameter, were taken to Limodra. Here, after exposure to the sun for two or three months, they were fired. The effect of this heating was to turn cloudy brown and yellow shades into clear bands of white and red and also to intensify orange tints into reds; the hue of the red carnelian so obtained might range anywhere between the palest flesh colour and the deepest blood red; the latter variety when free from cracks and flaws being the most highly prized. From Limodra in the old days the stones were taken down the Narmada to Broach whence they were shipped to Cambay.

In the heyday of the Cambay trade, about the middle of the nineteenth century, about 600 families of skilled workers and from 500 to 600 labourers found employment in it. An elaborate guild or *panchayat* system existed, each concerned with some particular group of operatives; thus the workers on the lapidaries' wheel, the drillers, the polishers and the dealers each had their separate union.

The Chinese, Arabian and European markets absorbed most of the production. The former demanded carnelian ornaments solely, flat stones cut into ovals and squares to be worn as armlets or dress decorations, and necklaces of polished round beads. For the Arabian trade ring stones, necklaces, rosaries, wristlets and armlets of agate, carnelian, cat's eyes and bloodstone were made; the necklace beads being diamond-, almond- and spear-headed shapes; the wristlet stones either flat or cut into fanciful shapes. A great variety of articles were made for the European markets including slabs for boxes and inlaid table tops, cups and saucers, chessmen, flower vases, card, letter and pen racks, watch stands, ink stands, knife handles, rulers, paper knives, pen holders, necklaces, bracelets, brooches, paper weights, knitting needles, shirt studs, ring stones and specimen rough stones polished on one side.

The output of stones from the Rajpipla mines, which were farmed out by the State, used to vary between 100 and 500 tons per annum. They were closed down in 1917, but yielded 148 cwt. again in 1929. Small-scale and probably surreptitious operations probably still take place from time to time; for instance, Dr Sahni found 'heaps of freshly decrusted agates' lying in the neighbourhood of the Ratanpur pits in 1943.

Although the bulk of the material used in Cambay came from Ratanpur other places also supplied their own specialities. These included veined agates from Ranpur, in Ahmedabad district, and bloodstone, or heliotrope, and moss agates from various places around Morvi, in Saurashtra. The bloodstones are subtranslucent, dark green chalcedony speckled with red; the moss agates pale grey or whitish, perfectly translucent stones, through which the delicate tracery of a dark green mineral (glauconite?), sometimes turning a reddish brown, simulates moss-like growths.

Onyx, with straight, even, parallel bands of grey and white, black and white, or translucent brown and white colours is common at Ratanpur and both it and the banded red and white sardonyx are to be obtained in Jabalpur. Sard, the yellow or brown carnelian, occurs at Ratanpur and elsewhere. The common white chalcedony of the Deccan Trap sometimes passes into the translucent bright green plasma, or the apple-green variety known as chrysoprase; by gradations of tint the dull, leek-green prase is formed which passes in its turn into bloodstone. Occurring with them are many kinds of jasper, the impure, opaque form of cryptocrystalline silica, either single-coloured or banded, ideal stones for seals and signet

rings: dark greens, brilliant reds and bright yellows are the commoner tints.

The term 'jasper', as generally used by Indian geologists, refers to a rock rather than a mineral species, and banded rock jaspers are common in the Dharwar and Bijawar formations throughout the peninsula. Pebbles derived from them are common in river beds. Only one reference to many scattered through Indian geological literature is possible here. Near Timappaghar, in the Sandur taluk of Bellary district, Mysore, there are great cliffs, 300 to 400 feet in height, formed of banded jasper-haematite of vivid red and purplish grey, or greyish brown tints in stripes, often exquisitely vandyked. The jointing is rectangular and blocks from a foot cube to some cubic yards in bulk could easily be quarried. Bruce Foote described it as a most richly coloured rock which even in the rough formed a material of great beauty.

Of unusual interest amongst the chalcedonic stones is the 'pagoda stone' of Burma, a semi-transparent, greyish white onyx which occurs only in certain particular beds of amygdaloidal lava flows from Popa, the extinct volcano of central Burma. When cut transversally, the truncated bands exhibit a realistic outline of a Buddhist pagoda in miniature and then bring prices far beyond those obtainable for any other form of chalcedonic quartz of similar size.

OPAL

Opal is a form of amorphous hydrated silica, $\text{SiO}_2 \cdot n\text{H}_2\text{O}$, in which the percentage of water is usually less than ten. Although its name is derived from the Sanskrit *upala*, or 'gem', the precious varieties of opal, including those with a characteristic play of colours, and the flaming red 'fire opal', are not known to occur in India, Pakistan or Burma today. It is true that Mallet examined very fair specimens of precious opal in 1886 which he had reason to believe came from the Deccan Trap, and that earlier authorities still write of specimens 'partaking of a reddish fiery effulgence' from Hyderabad, and of others as 'milk-opal with a flame-coloured tinge in transmitted light', from the Poona district of Bombay; yet the fact remains that all the later references to this stone are concerned with common opal or with one or other of its numerous modifications.

Opal is prevalent in parts of the Deccan and Rajmahal Traps in which it is found as nodular amygdules of varying sizes, usually either as opaque milky white or translucent bluish white types. The transparent, glassy variety, hyalite, has also been reported to occur in small amounts, while the opaque porcellanoid cacholong is not unknown. Opal is not infrequent in manganese ore deposits and may then assume shades of brown, pale green and light pink.

CRYSTALLINE QUARTZ & ROCK CRYSTAL

The semi-precious forms of crystalline quartz found in our countries include rock crystal and rose quartz, cairngorm and smoky quartz, citrine or yellow quartz, the chatoyant variety known in the trade as cat's eye and amethyst. Aventurine is best included here although it is really a quartzite. The use of rock crystal as an ornament in India dates from the prehistoric copper-age times, for beads fashioned from the mineral have been found in tombs of this period in Bihar. From the time of the Maurya dynasty (322-185 B.C.) onwards, rock crystal urns and caskets, vases and pitchers have formed part of the royal treasures of Indian emperors. Today, however, rock crystal has assumed a new importance transcending all its earlier applications and dependent on its unusual piezoelectric properties. When quartz crystals are subjected to mechanical pressure in the direction of any one of their three axes of binary symmetry, electrical charges are developed at the ends of these axes; conversely, electrical charges applied in such directions cause the crystals to expand and contract, and with alternating currents the crystal is set into mechanical vibration. This power of maintaining a constant rate of vibration has led to the use of quartz oscillator plates to stabilize and control frequencies in radio and television transmission, and in telephone and cable equipment, where they permit the simultaneous transmission of many independent messages over the same wire. In addition to their uses as telephone filters and resonators, they are indispensable in radar work, depth-sounding apparatus and acoustic anti-submarine devices. They also find a place in various types of quartz clocks which keep correct time to a few hundredths of a second per month, in range finders and in instruments for measuring pressures, as, for example, in gun barrels and aircraft engines.

The last war led to a phenomenal demand for quartz crystals for strategical purposes and it was met mainly from Brazil, whence the exports in 1943 reached a peak of 2,372 tons; in the same year, to give some idea of their applicability, the production of piezoelectrical devices in the United States of America alone amounted to over 14 million small oscillators, nearly 8½ million large oscillators, more than 65,500 telephone oscillators and over 24,000 units of detection equipment.

Only the finest rock crystals are suitable for these purposes and they must be free from cracks, flaws, irregular growths and inclusions, as well as from both optical and electrical twinning. No sources of such crystals have yet been found in India, Pakistan or Burma, but there is always the possibility of their discovery. Though it is now practicable to use smaller crystals than formerly for some types of work, they should not be less than 1½ inches in diameter and of flawless quality. Among localities deserving further search is a belt of country about 25 miles long and 5 miles broad, to the south of the Basipara-Hatibara-Meghpal Hills, in

Sambalpur, Orissa. Some of the Brazilian material comes from pegmatite veins, and quartz crystals from the mica-bearing pegmatites of Bihar, Nellore and Rajasthan, as well as those from the great pegmatite vein at Sakangyi, Katha district, Upper Burma, are worth further examination from this point of view.

From the Sakangyi pegmatite enormous rock crystals have been obtained; three of these were sold in Mogok about 1923 for £1,530, their total weight being nearly $1\frac{3}{4}$ tons. From one of them a clear sphere of rock crystal, $12\frac{3}{4}$ inches in diameter, now in the United States National Museum at Washington, is believed to have been made.

Rock crystal is cut for cheap jewellery in both Madras and Kashmir, and from unknown localities in the latter come excellent crystals of smoky quartz which are often pierced by fine acicular crystals of rutile. The small, doubly terminated, limpid rock crystals from the gypsum of the Salt Marl, near Kalabagh, on the Indus, in the Mianwali district of West Pakistan, are collected and sold to be made into necklaces. Disused rock crystal quarries exist at Nawai, in Jaipur, and at Hathuna, in Tonk, Rajasthan. Pebbles of amethystine quartz, smoky quartz, citrine and cairngorm of clear sherry yellow to dark brown tints, weathered from a plateau of Cuddalore Grits, occur on the surface and in the beds of local streams, near Vellum, in the Tanjore district of Madras, and at one time formed the basis of a stone-cutting industry there engaged in the manufacture of brooches and other useful and ornamental articles. Fine quartz cat's eyes exhibiting the opalescence or chatoyance of the true cat's eye, a variety of chrysoberyl, come from the Malabar Coast and from Rajpipla. Amethyst, the purple to violet variety of rock crystal, occurs rather rarely in drusy geodes of both the Deccan and Rajmahal Traps, as, for instance, with chalcedony in the basalts, 2 miles west of Burhait, in the Santal Parganas. The stone has also been reported from several places in the Sutlej valley of Bashahr, one of the former Simla Hill States, from the Nellore mica belt, from Kangayam, in Coimbatore, and from surface detritus near Kollengode, Palghat taluk, Malabar. The colouring of Indian amethysts is often uneven, patchy, striated and zoned but better stones without these defects have been seen at Mogok, Burma. Massive, transparent to translucent rose quartz is obtainable in large quantities from certain localities in India, especially in regions where manganese ores are found. 'When sufficiently clear and transparent,' writes R. Webster, 'which is rare, rose quartz makes a fascinating gem and several specimens mounted in jewellery are known, but most rose quartz is used for small carvings, figurines and for pendants and small *objets d'art*.' Associated with many of the pegmatites of the Bihar mica belt there is abundant rose quartz of translucent pink and rose colours. When polished this material assumes a most pleasant depth of texture. It is eminently suitable for carved ornaments or for small

decorative panels, and is particularly plentiful in the mica mines to the north-east of Parsabad, but both here and elsewhere it is thrown away on the dump heaps. In the Mogra synclinalorium of the Chhindwara district, Madhya Pradesh, rose quartz is so prevalent that, according to Sir Lewis Fermor, large quantities could easily be collected. In the same district, at Khairi, there is a quartz vein 25 feet in width, which in many places contains material of pink to deep rose shades in the normal translucent to milky white quartz. Again, on the Dudhara Hill, also in Chhindwara, loose blocks of amethystine and pink quartz are obtainable. In the manganese mines at Kodur, in the Srikakulam district of Andhra, pale violet and pale reddish vein quartz has been found.

Max Bauer in his work on *Precious Stones* writes: 'Fine specimens of aventurine are occasionally met with in India, but nothing definite is known as to their mode of occurrence or the exact locality. A very pretty, green, glistening variety from the Bellary district of Mysore deserves mention; the scales of mica enclosed in it are of the green chromiferous variety known as fuchsite, and the mineral itself occurs in blocks from which slabs of considerable size can be cut.' This green quartzite actually occurs in a low ridge a few score yards south-east of Metri, on the road between Daroji and Kampli, Bellary district, Mysore. A uniformly rich bluish green quartzite is found near Belvadi, Hassan district, while a banded green variety occurs near Sindagere, about three miles north-west of Belvadi. Green quartzites of Dharwar age are also common in the Bensibetta ridge, the Karayanbetta Hill, and other localities in the Coimbatore district of Madras. Five miles to the south of Kandukur, in the Nellore district of the Andhra State, there is a very glassy, large-grained quartzite of a delicate pale, aquamarine-green colour banded with discontinuous laminae of a deep purple tint. Bruce Foote stated that if cut and polished this stone would be of quite extraordinary beauty for decorative purposes. Green quartzites containing chrome-vanadium muscovite form two parallel ridges passing through Mahalgaon, Bhandara district, Madhya Pradesh, according to S. K. Chatterjee. It has been stated that green aventurines of these types are esteemed in China and are sometimes used as substitutes for jade and jadeite, but specimens from southern India given to jadeite cutters in Tengyueh, Yunnan, excited little interest on account of their brittleness. Dr A. M. Heron has described smooth, pale and dark green, ovoid beads, sold by jewellers in Rajasthan and Kashmir as 'beryl' and 'jade' respectively, which on examination proved to be fuchsite quartzite. A similar material, after treatment with a suitable dye, passes as 'pink topaz'. A vase fashioned from a green mica rock has been found at Mohenjodaro. It is apparently pure fuchsite and is stated to be not later than 2750 B.C.

ORNAMENTAL FELDSPARS

Large crystals of the beautiful bright green, opaque or very slightly translucent variety of microcline, a potassium aluminium silicate, known as Amazon Stone, occur with pink and blue tourmalines in the druses of a cavernous pegmatite, two miles south of Domchanch, Hazaribagh, Bihar. It has also been found in the Lakshminarayana, Kubera and a few other mica mines in Nellore district, Andhra State. In other countries this feldspar is utilized for cabochons, beads and pendants, but it does not appear to have been cut in India.

Moonstone is the most important semi-precious member of the feldspar group and its characteristic sheen, or schiller, is caused by the reflection of light from its microlaminated structure, usually but not invariably of orthoclase and albite. Ceylon is the chief source of supply and for many years the mineral was won from leptynites of the Khondalite Series, in the Dumbara district of the Central Province. More recently the crude material has been obtained from kaolinized pegmatites near Ambalangoda, in the south-west of the Island. Such conditions are doubtless to be found if sought for in southern India, indeed a moonstone-like opalescence frequently characterizes the feldspars of the more coarsely crystalline charnockites. At some localities in the mica belt of Bihar, near Bagjunt, in Hazaribagh, for instance, the feldspars of the pegmatites have the same appearance and might be utilized for cheap jewellery. The augite-diorites of the Lar Koh, Chagai district, Baluchistan, contain large crystals of oligoclase which, according to Vredenburg, 'exhibit a beautiful blue iridescence similar to that of some varieties of moonstone'.

Moonstone is plentiful in the Ruby Mines Tract of Upper Burma, indeed a large pegmatite vein several feet thick is composed of quartz and orthoclase with an unusually remarkable schiller, and was formerly worked for moonstone on the Myo Taung, 4 miles east-north-east of Mogok. Again, the feldspar crystals of one type of the augite syenites of the Kyaukthinbaw Taung possess a beautiful moonstone schiller. Water-worn stones come from the gem gravels and cut locally *en cabochon* often exhibit the much prized, lovely, bluish bloom which distinguishes the best varieties of the stone. The yellow or orange coloured orthoclase feldspar, known to the Burmese as *shwe myaw*, or golden moonstone, also furnishes attractive specimens. Wadia and Fernando, writing of Ceylon moonstones, state that those with a sky blue to deep blue schiller are the most valuable, followed by bluish white kinds and then by a third group with a silky to pearly white sheen. The stones are always cut *en cabochon* and the best effect is not obtained unless its base is exactly parallel to the lamination. Blue, iridescent varieties of the plagioclase feldspar, labradorite, derived from the local syenites, are also occasionally cut for sale in Mogok.

Murchisonite is a variety of orthoclase feldspar which sometimes forms thick beds and seams of massive and granular kinds in the garnetiferous feldspathic rock edging the alluvium and stretching from the Krishna district into Visakhapatnam, Andhra State. 'The feldspar is generally a reddish or pale salmon colour, weathering lighter, but it is frequently of a decided red, even rosy-red, and then, on well-worn and smoothed surfaces it has somewhat the look of rhodonite, while it has always a fine pearly, silvery or bright bronze sheen' (W. King).

Murchisonite and sunstone, or aventurine oligoclase, which possesses a spangled appearance with internal reddish gleams, due to its inclusions, have both been recorded from Mogok.

AMBER

Dr Berthold Laufer, a learned sinologue, proved from Chinese sources that the exploitation of the amber mines of northern Burma must date back to at least the first century of the Christian era, if indeed they were not worked in far anterior times. The earliest European account was given by the Jesuit Father, Alvarez Sernedo, in 1643, but the fact that both he and the early Chinese writers from the third century onwards refer to Yungchang Fu, a city in Western Yunnan, as the source of the amber, means no more than early statements that Golconda was the home of India's historic diamonds. Just as Golconda was merely a centre of the diamond trade, so Yungchang Fu was only the transit mart for amber passing from Burma to China. In almost all the early Chinese literature dealing with Burma it is said that the amber production of the country finds a place.

The mines themselves lie around Maingkwang in the Hukawng valley, through which the headwaters of the Chindwin river flow, a wild and inaccessible tract which was never brought under administration in British times. Visitors to the mines have been thus few and far between and include Hannay (1836), Griffith (1837) and the geologists Noetling (1892), Murray Stuart (1920) and Harbans Lal Chhibber in 1930. Dr Chhibber reported that the largest active centre was at Khanjamaw, and here, as elsewhere, the fossil resin which sometimes contains the incased remains of insects occurs in pockets in blue sandstones or dark blue shales with carbonaceous impressions. These rocks are of Eocene age and very thin coal seams are sometimes associated with them. Shallow pits are dug on the outcrops of these beds and the best amber generally occurs at depths from about 30 to 50 feet, in elliptical or oval pieces. During the rainy season some material is recovered by ground-sluicing the overburden of the outcrops. Mining methods are haphazard and primitive in the extreme; the labourers themselves being a motley lot of Kachins, Shans, Nagas, Maingthas and Chinese. Their results are largely a matter of

luck and it is not surprising that the output fluctuated within wide limits. Thirty or forty years ago it ranged between 100 and 200 cwt per annum; for the five years ending 1928, the average annual production was 49 cwt, but for the corresponding period ending 1933, this had fallen to 6.8 cwt. The right to collect a 5 per cent *ad valorem* duty on amber was 'farmed out' in British times with the jadeite royalties, the amber mines of the Hukawng valley being about 5 marches from Mogaung, in the Myitkyina district and the centre of the jadeite industry. It would be difficult to imagine a system more calculated to encourage clandestine dealing and evasion, with the result that the production figures for both these valuable minerals are completely unreliable.

Burmese amber, or burmite, is slightly harder, tougher and of higher specific gravity than Baltic amber, or succinite. It occurs in many shades of colour varying from pale yellow, through reddish tints to very dark browns, no less than fourteen separate varieties being recognized in the local trade, depending mostly on colour changes. Some of these, translated by Chhibber, are named 'honey', 'flame', 'sesame', 'horse-hoof', and 'light red', while in the darker shades there are at least four distinct kinds. Characteristic of burmite is its strong fluorescence, which appears as a bluish tinge in daylight and is powerful enough to impart an unpleasant greenish smeariness to some fine yellow specimens when viewed at a certain angle; on the other hand it adds to the beauty of some of medium browns. Much of the raw material from the mines is opaque, discoloured and crossed by calcite-filled hair-cracks, rendering it of little economic value.

At the time of Dr Chhibber's visit much of the amber was being cut into Kachin and Shan earrings and taken into Assam to be sold amongst the Naga tribes. Another portion made its way through Kamaing or Mogaung across the frontier to Tengyueh, to be cut there into a wide range of articles with the common blouse button at one end of the scale and small carvings of vertu at the other. Yet another portion reached Mandalay, to be fashioned into beads for the rosaries of the Buddhist priests, *nadaungs* (the ear cylinders worn by Burmese women), brooches, cuff-links, buttons and a host of trinkets in general. Burmese amber beads are familiar objects in the bazaars of the larger Indian cities, but there are many excellent imitations, mainly plastics (phenolic resinoids of the bakelite type) to attract the unwary purchaser.

APOPHYLLITE

Apophyllite finds a place in some textbooks on gems and ornamental minerals though the reasons for this are obscure, for though it is found in crystals which possess a perfection of their own, these are of more interest in the show cases of museums than elsewhere. It is a hydrous silicate of calcium and potassium, which

sometimes contains a little fluorine, $\text{KFCa}_4\text{Si}_5\text{O}_{20}\cdot\text{H}_2\text{O}$, and is often classed with the zeolites. A member of the tetragonal system, it is of varied habits, acutely pyramidal, tabular, or, and more commonly in India, in square prisms which give it a cubical appearance. It has a perfect basal cleavage with a pearly lustre, otherwise it is vitreous and its hardness is not much above that of fluorite. Colourless to milky white, it may have yellowish, reddish or greenish tints and is generally transparent to translucent.

Apophyllite is a common mineral in the geodes of the Deccan Trap from which the world's finest specimens have come, some of the four-sided prisms with terminal planes being as much as three and four inches across. 'The colour of the Deccan apophyllite', writes Blanford, 'is usually white, more rarely pink or green; some crystals are perfectly transparent, and one of the most magnificent associations of minerals to be found anywhere is seen when, as occasionally happens, perfectly clear vitreous crystals of apophyllite, of large size, are inserted on a mass of orange stilbite.' The best crystals of apophyllite, as well as those of a large number of other very beautiful, zeolitic minerals, are usually obtained during deep excavation work through the flows of the Deccan Trap—road cuttings, railway tunnels, well sinkings and so forth, but in spite of their great interest to the mineralogist they are of no significance in the jewel trade.

BOWENITE

Bowenite is an unusually hard, massive variety of serpentine of various shades of green, some kinds of which resemble true jade very closely; indeed for some time the mineral was actually called nephrite. Bowenite bijouterie, necklaces, earrings and trinkets generally are obtainable in many Indian bazaars and are traded about the country by travelling pedlars, usually from the North-West, who invariably describe their wares, probably in all good faith, as 'jade', for to distinguish such finished ornaments without causing injury to them would, in many cases, tax all the skill of an experienced mineralogist.

The mineral is mined in the Safed Koh, the frontier range between Pakistan and Afghanistan to the west of Peshawar, whence it is brought down to Bhera, in the Shahpur district of the Punjab, to be cut for sale. Sir Henry Hayden described another occurrence not far from Kabul as apple-green in colour, its large patches several inches in width, 'showing up very beautifully on the background of white and creamy marble'. A dark green variety is said to be found in Khotan (the most important provenance of true jade), both minerals being brought across the frontier and sold together in the Srinagar bazaars.

Bowenite is also found in the vicinity of Shigar, in Baltistan, the northernmost canton of Kashmir, among rocks of doubtful age, at an elevation of over 18,000 feet, so that mining is limited to two

months in the year. Cups, bowls, small vases and similar articles were, and perhaps still are, manufactured at Shigar from the translucent apple-green stone from this neighbourhood which occasionally shades into bottle-, grass- and dark green colours and, more rarely, into sulphur yellow. Mottled and veined, dark and light green, semi-precious serpentines occur at other localities in Kashmir and elsewhere, as, for example, in the Pulivendla area of the Cuddapah district of Andhra, but they have so far attracted no attention from lapidaries. Hard, compact, transparent, dark and light green bowenite occurs in small amounts with calcite in Aravalli rocks in the Bamanvada-Jeshangpur region of Idar, Bombay.

DIOPSIDE

The use of diopside as one of the uncommon gem stones and the characters of its crystals have already been outlined. It is mentioned here because of its occurrence in a massive condition, in thick and continuous beds in the Bamanvada-Jeshangpur area of Idar, Bombay, which, in the words of C. S. Middlemiss, 'are peculiar to this part of India and probably a rare occurrence anywhere, as distinguished from igneous pyroxenite masses which usually are of higher specific gravity, contain more iron and are darker coloured'.

It is exposed continuously for $\frac{3}{4}$ mile on the right bank of the Meshva river, about 1 to $1\frac{1}{2}$ miles south-south-west of Bamanvada, interbedded with calcite and pale amphibolite rock. Other widely separated, partial outcrops roughly follow a north and south line between Bolundra and Abharpur, a distance of about 10 miles, but, owing to alluvium, it is impossible to be certain whether all represent the same or different beds.

Individual beds of the mineral are 2 or 3 feet thick, totalling 8 feet in one section and 30 feet in another, composed of very coarse to medium-grained, white, creamy white or pale whitish grey diopside. The purer bands show nothing but this one mineral, except its change in a few places to tremolite, or to pretty, translucent green amphibole, compact and extremely tough.

At one locality in the chief exposure near Bamanvada, some of the associated calcite veins contain the transparent, dark and light green bowenite already mentioned on another page. This in all its physical and optical properties reproduces the veritable *sang-i-yashm* of the Safed Koh, which is brought down to Bhera and cut there for sale as 'jade'.

The more compact bands of the diopside rock when cut into slabs about $\frac{1}{2}$ inch thick are subtranslucent in creamy, pale green and occasionally pinkish tints. With a hardness of 5 to 6 it is an easily worked material, yet a polished surface is not lightly scratched and the rock should be useful as an ornamental stone and for small carvings.

FLUORITE

The cubic fluoride of calcium, CaF_2 , occurs in a great variety of colours; blue, green and amethystine, violet, rose-red and yellow, as well as more rarely in colourless crystals. The mineral, however, is far too soft for a gem stone as it occupies only the fourth position on the scale of hardness; moreover, it has a perfect octahedral cleavage. At the same time, massive varieties such as the Derbyshire 'Blue John', patterned in curved bands of purplish blue, violet, white and yellow, have been cut into vases and similar ornamental objects from Roman times onwards. The finest-quality colourless crystals bring high prices for use in optical workshops. Their low refractive power and weak dispersion, coupled with an absence of pronounced birefringence, lead to their employment in the manufacture of apochromatic objectives for microscopes, prisms for spectrographs and parts of the lens systems of telescopes.

An account of the occurrences of the mineral in India has been given under FLUORSPAR.

IDOCRASE

Idocrase, or as it is sometimes termed, vesuvianite, is a complex hydrous silicate of calcium, aluminium and magnesium with some replacement by iron. Its formula is now given as $\text{Ca}_{10}\text{Al}_4(\text{Mg,Fe})_2\text{Si}_8\text{O}_{34}(\text{OH})_4$, but boron and fluorine are present in some varieties and others contain beryllium. Crystallizing in the tetragonal system, its well developed, prismatic-pyramidal forms recall those of zircon, though two sets of prism faces as well as a basal pinacoid, seldom seen in the latter mineral, are often present. Striated prism faces are also common as are columnar and massive forms. Its colours are various shades of subtransparent to subtranslucent browns, greens and yellows; more rarely, blue. Vitreous to resinous in lustre, it does not cleave readily and possesses a hardness rather below that of quartz. It has a high refractive index, extremely low birefringence and very weak dichroism. Golden brown varieties from Canada are said to make lovely stones when faceted. The green and yellowish brown stones might be mistaken for diopside and epidote when cut. A compact green variety known as californite resembles jade, while xanthite is a yellowish brown idocrase from New York and cyprine a blue kind from Cyprus.

It is usually found in crystalline limestones; for example, at Dharol Hill, in Idar, Bombay, there are bands of massive, dark, clear brown idocrase, several inches across, at a junction of calc-gneiss and granite. Similar bands are associated with quantities of small grossular garnets, $\frac{1}{4}$ mile north-north-west of Nadri in the same region. Near Mundeti, also in Idar, prisms of bright brown idocrase up to an inch in length and $\frac{1}{4}$ inch in diameter, occur in

hornstone. Reddish idocrase in association with yellow-green epidote and quartz have been reported from a vein at the junction of limestone with a large basic dyke, south of Pind, in the Nimbahera region of Tonk, Rajasthan.

JADEITE

Jade is the name popularly bestowed on two separate stones which mineralogists distinguish as nephrite, or jade proper, and jadeite. The latter is a monoclinic pyroxene, a silicate of sodium and aluminium, $\text{NaAlSi}_2\text{O}_6$; the former a monoclinic amphibole, a tough, compact variety of tremolite and a silicate of calcium and magnesium, $\text{Ca}_2\text{Mg}_5\text{Si}_8\text{O}_{22}(\text{OH})_2$. On account of its colours, toughness and supposed magical properties, jade, in the inclusive sense, has been cherished by mankind from prehistoric times onwards. Examples of this cult are found all over the world, but it must suffice to state here that it was cut into beads by the inhabitants of the Indus valley, between 4,000 and 5,000 years ago, and by the Sumerians of southern Babylonia, from 3,500 to 3,000 years before the Christian era. It is in China, however, that the appreciation of jade reaches its highest intensity, and from times long before the Shang dynasty (1766 — 1122 B.C.), the stone has left a record of significance touching most branches of Chinese social polity as well as expressing their high artistic achievements. To the modern Chinese, as it was to his ancestors, the stone is an emblem of virtue, integrity and honour. Throughout the centuries China has unquestionably absorbed almost the whole of the world's output of jade and jadeite, and it is only within comparatively recent times that adequate recognition of the subtle beauties of Burmese jadeite has grown in other lands, where it now forms a coveted article of feminine adornment.

Burma holds a world monopoly in jadeite. Tradition relates that it was discovered accidentally in the thirteenth century by a Yunnanese muleteer who picked up a stone to balance an animal's uneven load, but it was probably known long before that period. The modern trade dates from 1784, following the conclusion of protracted hostilities between Burma and China, the stone being then transported by the overland route between the two countries until 1841. The wars between England and China in the intervening years resulted in temporary set-backs until about 1861, since when the bulk of the production, though by no means all, has followed the sea route from Rangoon to Canton. The kings of Burma collected dues from the dealers, and with the British occupation of Upper Burma, in 1886, the right to collect the authorized one-third of the value of the stone removed from the mines was auctioned out annually to the highest bidder. The pernicious consequences of such a system have already been mentioned under amber: as regards jadeite the opinion of a

Deputy Commissioner of the Myitkyina district, as recorded by Dr H. L. Chhibber, may be quoted: 'From the time it is won in the Jade Mines area until it leaves Mogaung in the rough for cutting, there is much that is underhand, tortuous and complicated, and much unprofitable antagonism. In my opinion the whole business requires cleansing, straightening and the light of day thrown on it.' Higher authority did not introduce these salutary processes with the result that by 1930 jadeite mining was languishing.

The main jadeite occurrences lie in an area of 80 or 90 square miles on a deeply dissected upland among the hills of the watershed between the Chindwin and Irrawaddy. The Uyu, a tributary of the former river, flows along the foot of this highland, often through deep gorges. Its banks and the valleys of its small feeder streams are worked extensively for alluvial and detrital jadeite in both Recent and Tertiary deposits. The whole area lies within the Mogaung subdivision of the Myitkyina district of Upper Burma. Tawmaw, an important mining centre, is about 68 miles by road north-west of Mogaung, on the Sagaing-Myitkyina branch of the Burma Railways. Accounts of the industry were given by Griffith in 1847, Noetling (1893), Bleek (1908), and by Chhibber, an officer of the Geological Survey of India, between 1928 and 1931. Dr Chhibber's production of a geological map of this difficult region, covered as it is by almost impenetrable jungle and infested with insect pests, was a pioneering effort of the highest merit and must form the basis of any future attempts to resuscitate jadeite mining on modern scientific principles.

The alignment of the known jadeite outcrops leads to the belief that there are at least four jadeite-albite dykes, or sills, intrusive into an extensive complex of peridotites (dunites, mica-, hornblende-, diallage-peridotites, pyroxenites and amphibolites), which in places have been partially or wholly converted into serpentine. The Tawmaw dyke was under active exploitation in Dr Chhibber's time, on an outcrop some 300 yards long and 200 yards wide, but this is not its whole extent as it comes to the surface again, usually exposing jadeite, in four or five places over a lateral extent of some five miles. The two operating mines at Tawmaw were the Dwingyi and the Kadon Dwin, and at the six shafts of the former work was only possible between March and May, for during the rainy season the shafts filled with water, and the clearance of water and mud occupied the period between November and the end of February. The Kadon Dwin was a modern mine managed by C. W. Chater of the Burchin Syndicate, properly laid out with drives along the dyke from a shaft about 50 feet deep. Compressed air supplied power for the rock drills, and pumping machinery had been installed. By these means it was possible to remove the whole of the jadeite lenses, which occur mainly in albitite along the foot wall. For further details and for an account of the

numerous workings in certain Tertiary deposits which fringe the serpentine massif; in the thick, sub-Recent Uyu Boulder Conglomerate and from the alluvial deposits of the Uyu itself, the writings of Dr Chhibber should be consulted. He divides the jadeite-bearing intrusions into three rock types—jadeitites, albitites and amphibolites. Jadeitite is an exceedingly tough rock, normally white, but sometimes irregularly streaked and spotted emerald-green, apple-green and lavender-blue. In some cases the rock consists entirely of jadeite and it then furnishes all the gem material; in others, large crystals of amphibole are also present. Intermediate in composition are the albititic jadeitites which grade into the albitites—granulitic rocks composed almost exclusively of untwinned albite. The 'amphibolites' are unfortunately named as they consist of primary amphibole and are not the metamorphosed basic igneous rocks with a granulitic texture to which the term is usually applied. These amphibolites, of which there are three varieties, contain nodules of the green chromium-bearing jadeite, and are themselves often rich in chromite.

Chinese dealers classify the stone into many kinds, the values of which vary greatly. This is not surprising in a mineral which may possess any colour from pure white through all the shades of green to amethystine, mauve, violet, lavender and light blue; yellow and orange to various tints of red, brown and the deepest green which in some lights appears black. The most highly valued is a uniform, translucent grass-green, best compared with the emerald in colour, or, as the Chinese say, with the green in a peacock's tail seen in sunlight. This, with the leek-, apple-, and pea-green kinds, as well as a translucent, light grape-green variety of remarkable clarity, are very expensive stones. Jadeite with a light green background, spotted or streaked with brighter green colours, ranks next, and with the former is used for expensive jewellery—rings, necklaces, earrings, pendants, brooches and so forth. The limpid whites, flecked and mottled with apple-green and similar shades, are also highly prized. The cheaper stones include the darker greens, mauves and the various tints of blue, orange and brick-red, yellow, rust-red and white, in order of value. Although objects fashioned from Burmese jadeite, such as beads, plaques, ring-stones and small carvings, are familiar enough in India, Europe and America, the real market for this particular stone is in Canton, where much of it is carved, though there was, and probably still is, a secondary centre in Tengyueh, Yunnan, mainly concerned with the manufacture of bangles. Some cutting was also done in Mogaung and Mandalay. It is not generally realized that in pre-war years between 100 and 200 tons of jadeite used to leave Burma every year, that the total imports of jade (including jadeite) into China at that time amounted to more than 6,000 tons per annum, and that in Peiping alone, leaving out of account the cutting and carving industries of Canton, Soochow,

Shanghai, Tengyueh and other places, there were over 600 establishments of various sizes engaged in business concerned with these stones.

The official returns of production of jadeite in Burma during the British regime are thoroughly unreliable; for the 15 years ending 1923, they indicate, for what it is worth, an average annual output of about 4,500 cwt. For the next five years, up to and including 1928, the annual average was given as 2,100 cwt, and for a similar period ending 1933, 2,382 cwt. Over the quinquennium ending 1938, output is stated to have averaged 1,857 cwt annually. The declared values are not given as they are believed to be misleading.

Conditions of tranquillity and general prosperity of China have always stimulated jadeite mining in Burma, but famine, floods and war have been reflected in depression. As far as the mineral deposits themselves are concerned they are capable of meeting any likely demand upon them, provided their exploitation is conducted on proper lines and not overburdened with ancestral methods of official control.

LAZURITE (LAPIS LAZULI)

In the family of minerals known as the feldspathoids, which take the place of the feldspars in certain rocks rich in alkalis and poor in silica, there are three members distinctive by reason of their vivid blue colours. They are lazurite, a silicate of sodium and aluminium with sodium sulphide, $3(\text{NaAlSiO}_4) \cdot \text{Na}_2\text{S}$; sodalite, a silicate of the same two elements, with sodium chloride, $3(\text{NaAlSiO}_4) \cdot \text{NaCl}$, and haüynite, a similar silicate with calcium sulphate, $3(\text{NaAlSiO}_4) \cdot \text{CaSO}_4$. Some mineralogists regard lapis lazuli as a complex aggregate of all three compounds; others classify it under lazurite, adding that it is probably contaminated with isomorphous intermixture of the other two. In any case, the natural rock also contains small amounts of calcite, various pale coloured pyroxenes, amphiboles and other silicates and, very frequently, pyrite. All three blue minerals belong to the cubic system and all are rather soft, coming between apatite and orthoclase in hardness.

Lapis lazuli was used but sparingly in the times of the Harappa civilization, between 3000 and 2000 B.C., in contrast to its widespread employment in Sumer, the southern kingdom of ancient Mesopotamia, approximately about the same period. The magnificent gold regalia from the royal tombs of Ur are decorated with it; oval gold bowls have lapis lazuli lugs; the hilt of a gold dagger is fashioned from a large single piece of the stone; it appears in inlay work on musical instruments and gaming-boards, was cut into small spouted cups, and, in the form of tesserae, set in bitumen in mosaic work. The great quantities found in the royal cemetery

are held to prove that even at so early a period a regular trade existed between Mesopotamia and the mines in Badakshan whence it was derived. In later and less prosperous times the waste from the lapidaries' shops of Ur was powdered and mixed with some binding agent before being used again. The employment of such reconditioned stone was very common in the Sargonid age about 2300 B.C. The uses of lapis lazuli in modern times do not differ greatly from those of these days before the dawn of history, for it is still cut into necklace beads and other jewellery, carved into costly vases and small ornamental pieces, employed for inlays and mosaic work, and in a powdered condition, before the discovery of an artificial substitute, ultramarine, in 1828, furnished the artists of the world with their most efficient blue pigment.

The Badakshan mines are in the valley of the Kokcha, a tributary of the Oxus, a few miles above Firgamu, where the mineral, occurring in veined black and white limestones, has been worked from an unknown antiquity. India, possessing no deposits of her own, doubtless acted to some extent as a mart for the Badakshan stone, retaining such supplies as she needed for her own uses throughout the centuries. Known as *lajward*, small quantities are also said to have been imported into the Punjab from Kashgar, but whether this came from a mine believed to exist in the Kultuk region of eastern Siberia is doubtful.

The lapis lazuli of Burma comes from the Mogok Stone Tract, where it is obtained mainly from hillside workings on both sides of the Dattaw *chaung*, a small side stream at the head of the Mogok valley. It is cut into beads for necklaces of azure, Prussian blue and indigo tints, both in Mogok and in Mandalay. Another pretty but less valuable variety exhibits flecks of blue on a white background, stated by Cotter to contain white pyroxene, wollastonite, scapolite and calcite. Burmese lazurite should not be confused with the sodalite which also occurs in the Stone Tract.

PREHNITE

This orthorhombic, hydrous silicate of calcium and aluminium, $\text{Ca}_2\text{Al}_2\text{Si}_3\text{O}_{10}(\text{OH})_2 \cdot n\text{H}_2\text{O}$, a relative of the zeolites, is usually found in botryoidal masses with a radiating structure, of pale, oil-green, olive-green and yellowish colours. In hardness it comes between orthoclase and quartz, and it is used for the preparation of small carvings such as pendants, when its resemblance to some varieties of jade is said to be very marked.

In spite of its zeolitic character it is a rare mineral in the amygdulæ of the Deccan Trap. Blocks of it have been found at the Kashmir sapphire mines, and spherical aggregates, intergrown with strontianite, occur in the Kharari valley of Las Bela, Baluchistan.

PIEDMONTITE

Piedmontite is a hydrous silicate of calcium, aluminium, iron and manganese, $\text{Ca}_2(\text{Al,Fe,Mn})_3(\text{SiO}_4)_3(\text{OH})$, a manganiferous variety of epidote containing from 3.5 to 10.5 of manganese. Of crimson, dark red, reddish black to black colours, it belongs to the monoclinic system, crystallizing in prismatic forms, or occurring in a massive condition. It has a high index of refraction, a very high double refraction and a striking pleochroism exhibiting yellow to orange, amethyst to rose and rose to carmine colours in thin section.

It has been found at several places in the Archaean schists of those parts of India where Gondite rocks prevail, as a rule in the crystalline limestones of the same neighbourhoods. It has also been reported from the phyllites of the Iron Ore Series of north Singhbhum. Nodules of piedmontite from Ghogara, Nagpur district, Madhya Pradesh, are often as much as three inches in width and sometimes display a parallel, fibrous structure, so as to resemble deep crimson silk. In an occurrence at Kajlidongri, Nagpur district, small prisms of a pansy-purple colour were obtained. In the vicinity of Pali, in the same district, piedmontite is abundant in many of the local limestones; in some instances in nodules up to one inch in length.

Piedmontite has been cut occasionally, probably as an uncommon gem for a collector's edification.

RHODONITE

Deriving its name from the Greek *rhodon*, a rose, this rose- or flesh-red silicate of manganese, MnSiO_3 , belongs to the triclinic system but is generally found massively compact; some carbonate of manganese, rhodochrosite, MnCO_3 , may then be present with it, as is the case at Gaimukh and Deir, in the Chhindwara district of Madhya Pradesh. Owing to its perfect cleavage it breaks easily into prismatic fragments which may be translucent or opaque with a vitreous lustre. In hardness it is about the same as orthoclase and it has a high index of refraction and a moderately high birefringence.

Rhodonite has been found at many manganese mines in Madhya Pradesh, Vindhya Pradesh, Bombay and Andhra, particularly in those associated with rocks of the Gondite Series. It has been used as an ornamental stone in other parts of the world especially in Russia. At the Manegaon and Risara localities, in the Nagpur district of Madhya Pradesh, there are considerable amounts of both rhodonite rock and of rose-pink rhodonite studded with orange-coloured spessartite garnet crystals, according to Sir Lewis Fermor. Much of the Manegaon material is too blackened to be of use, but a small proportion of oxy-alteration, provided it does not give rise to decayed spots, improves the beauty of the stones,

giving rise to mottlings, small patches, and moss-like markings. Considerable supplies of small pieces up to six inches across are available, but it would be hard to obtain larger pieces, say for table tops. Sir Lewis Fermor added that it would be difficult to find a more beautiful ornamental stone than the pink rhodonite, with its delicate veins of black manganese oxide, than that obtainable at Manegaon.

SODALITE

Sodalite might easily be mistaken for lazurite, with which it has many resemblances in colour, habit and composition. (See LAZURITE.) Its most important occurrence in India is in a few large and coarse pegmatites associated with the soda-bearing rocks of Kishangarh, Rajasthan. These pegmatites often carry big, rather rounded, individual masses of grey elaeolite, sometimes more than a foot in diameter, with finely granular, interstitial sodalite, either colourless or intensely blue, and occasionally accompanied by cancrinite.

In certain veins near Mandaoria, cancrinite, both in granular masses and large crystals up to a foot in length, occurs with sodalite and biotite. Another rock there consists of pure white feldspar, veined and mottled with deep blue sodalite, bright yellow cancrinite and shining black biotite, an unusual combination of colours in a bizarre arrangement most pleasing to the eye in polished specimens. Some of the colourless, transparent sodalite assumes a pink colour when kept in the dark for a few weeks, but it rapidly disappears again when exposed to light. When freshly broken in the field, the fractured surfaces of the colourless mineral are suffused with a carmine tint which vanishes in a few moments.

Sodalite of purple and of deep lilac tints, accompanied by pale green nepheline, occurs in a band of crystalline limestone near the Tajoungnadine mine, in the Mogok Stone Tract, and crystals of a simple, dodecahedral type have also been found there. These unusual colours are unhappily not quite permanent to long exposure to light, in contrast with the vivid blues of the Kishangarh minerals.

Elaeolite, the intimate associate of sodalite, is a massive variety of nepheline, itself a member of the feldspathoid family and a silicate of sodium, potassium and aluminium, approximating $K_2O \cdot 3Na_2O \cdot 4Al_2O_3 \cdot 9SiO_2$ in composition. It owes its name to the Greek word *elaion*, oil, in allusion to its greasy lustre. Its opalescent varieties have been used to a small extent as gem stones, presumably only for collectors' purposes. Kishangarh elaeolite is known to contain minute, platy inclusions arranged in parallel directions and deserves further examination from this point of view. Greenish yellow elaeolite from an urtite near Sinkwa, in the Mogok Stone Tract, cut *en cabochon*, at the request of one of the authors

of this book, though a striking and uncommon stone, failed to find any appreciation from the gem merchants in Mogok. If the mineral is ever wanted for carvings, or for ornamental purposes in India, rounded boulders of pure elacolite, oily yellow to yellowish brown in colour, are said to be of frequent occurrence in the debris of small hills west-north-west of Sivamalai, Coimbatore, Madras.

Cancrinite, also mentioned above, is yet another member of the feldspathoid family, a hydrated silicate of sodium, calcium and aluminium, related to the others in composition, associations and occurrence.

THULITE

Thulite is a beautiful rose or pink variety of zoisite, itself an orthorhombic mineral, and a calcium, aluminium silicate with nearly the same composition as epidote. It owes its red tints to the presence of manganese and its name to Thule, an ancient name for Norway where it was first found.

It occurs as rose-pink granular aggregates, fibrous patches, dendritic clusters and felted bundles of prismatic crystals, in a cancrinite-calcite rock lying between syenite and Aravalli limestone near Mandaoria, Kishangarh, Rajasthan. Thulite is sometimes cut *en cabochon* but has been used mainly as a decorative stone in other countries, and this Indian rock, white or pale grey, fine-grained and saccharoidal, with its scattered blotches of rose-pink and pinkish-yellow, might after polishing be utilized for a similar purpose.

A purple variety of thulite, strongly pleochroic from rose-red or violet to colourless, is associated with sillimanite and corundum at Pipra, Rewah. Sillimanite schists of the same locality contain purplish patches of fine thulite, and the sillimanite-corundum rock found there owes its purple colour to its abundance of the same mineral.

TURQUOISE

Turquoise ornaments are worn universally by the women of the Himalayas, from Bhutan in the east to Ladakh in the west; further north its employment is so widespread that it has been described as the national stone of Tibet, while in Kashmir the silversmiths employ it in a crushed condition as an inlay for their mosaic work. The use of turquoise as a gem stone, like that of lapis lazuli, dates from early prehistoric times, particularly in ancient Egypt.

In composition a basic, hydrous phosphate of aluminium, $\text{Al}_2(\text{OH})_3\text{PO}_4 \cdot \text{H}_2\text{O}$, it owes its lovely sky-blue to apple-green colours to variable but small amounts of copper. It is generally found in thin seams or encrustations of almost amorphous, very finely cryptocrystalline aggregates of minute grains, though very rarely it has been obtained in small, pinacoidal, triclinic crystals. Opaque for all practical purposes, it has a waxlike lustre and,

although no harder than orthoclase, takes a good polish. It is nearly always cut *en cabochon* or in round or oval forms, at any rate as far as the European and American markets are concerned. Turquoise matrix too, is often polished, and in such specimens the mineral is veined with its gangue material (often limonite), or disseminated through it.

Turquoise has not been definitely proved to exist in India; certain blue minerals once cut for ring stones in Ajmer and other parts of Rajasthan being in all probability copper ores. The only other possible indication of its presence is the statement of J. A. Dunn, that sometimes in the coarse veins of kyanite of the Rakha area of Dhalbhum, Bihar, 'small vughs are lined with a green incrustation. It is a copper-aluminium phosphate and is similar to turquoise'.

La Touche thought that most of the turquoise seen in India 'probably comes from the turquoise mines of Nishapur, Khorassan, Iran'. These lie about 32 miles north-west of Nishapur, a town some 40 miles west of Meshed. In the Records of the Geological Survey for 1884, General A. H. Schindler has given an account of the workings and of the methods used in the cutting and disposal of the stones. In 1885 they were visited by C. L. Griesbach, an officer of the Geological Survey of India. The turquoise is won from veins and crevices in contact rocks between metamorphosed grits, sandstones and limestones of Jurassic or Rhaetic age, with porphyritic trachytes, ashes and other volcanic rocks, and there are many hundreds of so-called 'mines', including the diggings in the detritus of the disintegrated rock stuff, washed down the ridges.

At the mines the stones were sorted into three main groups and all those of good and 'fast' colour (the most prized being 'the deep blue of the sky'), and of favourable shapes, were classed as *angushtari*, or ring stones. The second group, or *barkanch* stones, were further subdivided into four grades, the first and second of which went mainly to Europe, through Meshed and Russia, for use as ring stones. The remainder were sold to Persian jewellers and goldsmiths for encrusting amulets, daggers, sword hilts and sheaths, horse trappings, pipe heads, etc. All remaining stones were lumped together as *arabi* and consisted of poor-quality, pale-coloured, greenish and spotted material, some of which went to Arabia and some to Europe. Large flat pieces and slabs were made into amulets, belt fastenings, brooches and so forth. The stones of a greenish tint were bought principally by Afghans. India doubtless absorbed much of the Persian production, and in pre-war years was certainly taking the great bulk of the exports of both cut stones and turquoise matrix.

It is doubtful whether turquoise occurs in Tibet; some authorities assert that there are mines in the eastern part of the country, but, on the other hand, the explorer Sarat Chandra Das stated

that the best stones came from a mine in the Chang Chenmo range of Nari-Khorsum. This may be a continuation of one of the ranges bordering the Chang Chenmo valley of Ladakh, in north-eastern Kashmir. Other sources of turquoise are the ancient mines of Maghara and Serabit el Khadim, in the Sinai Peninsula of Egypt; the Los Cerrillos mountains of New Mexico, U.S.A., where it again occurs in an altered trachyte, and various other localities in the United States and in Russia.

ZOISITE

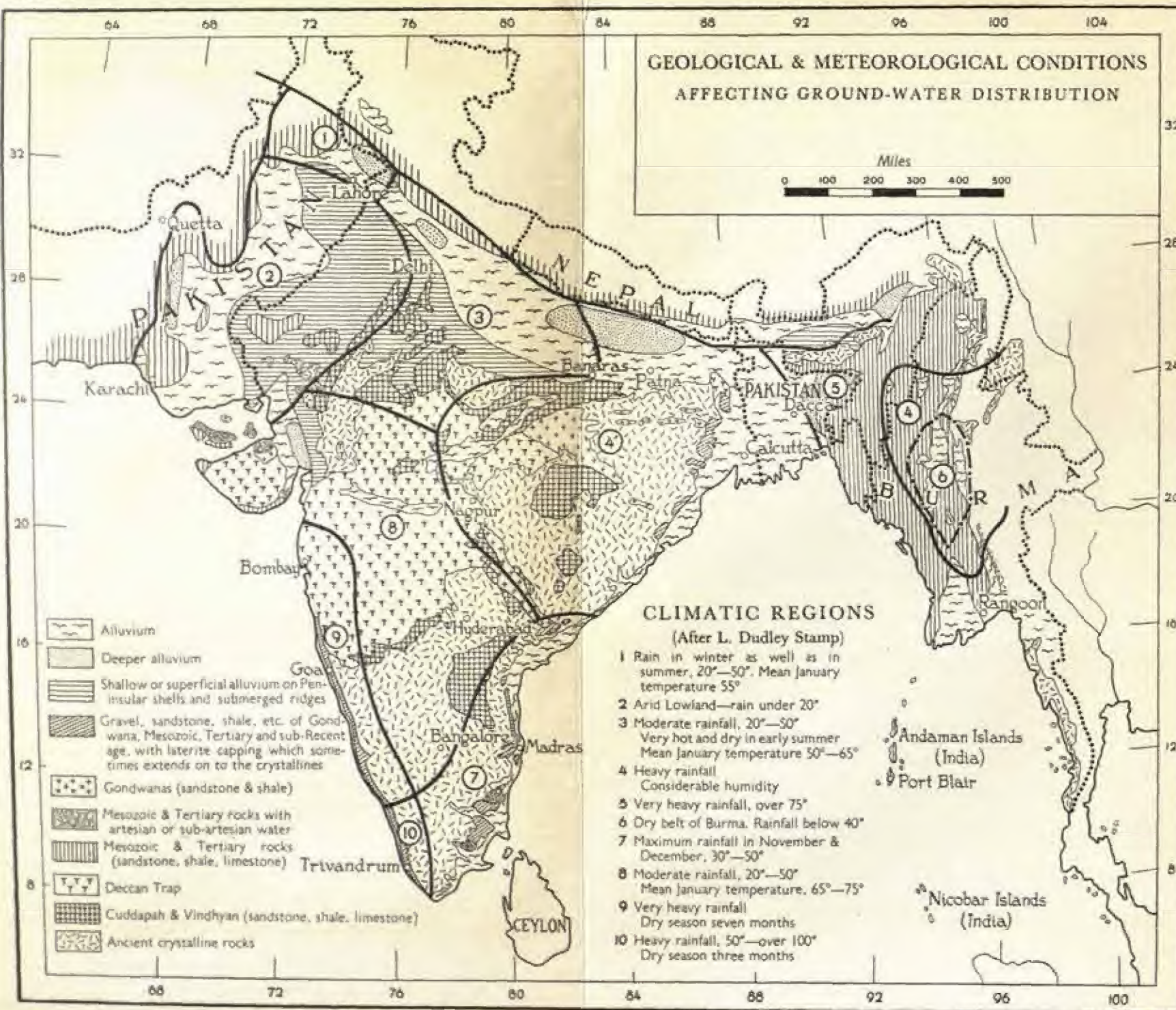
The manganiferous variety of zoisite, the orthorhombic, basic, calcium-aluminium silicate and a member of the epidote family, has been described under THULITE.

Zoisite itself has been found in loose blocks in the valleys to the north-west of the Sirsa La, in Zangskar, Kashmir, and their source is probably in the area of basaltic rocks which form peaks D.24 and D.25, as they are drained by streams to the west of this pass. It forms a heavy, whitish rock capable of taking a high polish, and was at one time collected by the local mountaineers and taken into Lahul, whence it found its way to the stone workers in Amritsar. The lapidaries in Srinagar, to whom La Touche gave specimens, found it too hard for them to work into ornaments.

McMahon examined specimens of the mineral, occurring as veins in serpentine, which had been collected by La Touche, and described its optical properties as agreeing with those of zoisite. Partly clear and transparent and partly clouded and opaque, it had a high index of refraction and a feeble double refraction.

PART V
WATER AND SOILS

1874
1875



CHAPTER XVIII

WATER SUPPLIES

It has been estimated that from two-thirds to four-fifths of the moisture precipitated from the atmosphere on to the surface of the earth in the form of rain, dew or snow, is evaporated back again or absorbed by vegetation: of the remainder a part finds its way into the rivers and the sea and another part sinks into the ground to augment the subterranean water of meteoric origin already there. Geologists also recognize two further underground groups—'connate waters' which were trapped in some sedimentary rocks during their deposition, and 'juvenile waters' which are of plutonic or magmatic origin, though these, being of but slight economic interest, will not be considered here.

Below a certain depth from the surface, which varies very greatly with the amount of the rainfall and with the lithological character of the subsoil rocks, the infiltrating moisture gives place to a zone of complete saturation, the upper line of which is known as the 'water-table' or 'hydrostatic level'. In spite of its names it is not a flat plane for it follows every undulation of the ground above, though on a less pronounced scale. It reaches the surface at the sea shore or on the edges of lakes, it rises below hills and falls below valleys, in dry regions such as Rajasthan its depth is far greater than in humid climates such as Bengal, in dry seasons it falls lower than it does during the monsoons, near rivers it fluctuates as they flood or shrink.

The quantity of water stored in the underground reservoirs depends on the permeability and porosity of the rock whose interstices it occupies, and if these take up a considerable proportion of the total volume, the amount so stored is proportionately great; this, however is not the whole story, for the size of the pore spaces of any particular rock determine to a large extent its capacity for the entrance and storage of water. Thus fine-grained clays and shales whose water storage capacity may be large are to all intents and purposes impermeable. Sands and sandstones, gravels and some varieties of conglomerate are good examples of porous formations, while indurated quartzites, crystalline limestones, slates and most of the igneous and metamorphic rocks can only act as permeable media when extensively jointed, fractured or crushed.

In the simplest conditions the water-table of a porous bed such as sand or sandstone, resting on an impervious layer such as clay

or shale, is in direct communication with the atmosphere immediately above it. Rain water then percolates through the soil, subsoil and the pores of the unsaturated rock to replenish the storage lower down. If an excavation is made in such a situation and carried below the local water-table, water will make its way into it and rise up to that level, forming a 'surface' or 'percolation' well.

The water-table of 'flowing' or 'artesian' wells is not in contact with the atmosphere immediately above them for they derive their supplies from remoter sources. In the oft-quoted textbook examples of the London or Paris basins, a permeable layer—the aquifer—lying between two impermeable beds has been folded into a syncline. Water enters the aquifer along its outcrops, which may be miles away from the centre of the basin, where, when its deeper parts are tapped through the overlying impervious beds, an overflow occurs at the surface owing to the hydrostatic pressure developed in the aquifer down the sides of the syncline. The height to which the water spouts, or flows, is dependent on the difference in level between the well head and the 'fountain head' or intake at the source of supply. Sub-artesian conditions are said to prevail when the hydrostatic head, though insufficient to raise a surface flow, yet causes the water to rise considerably in the boring.

The first Director of the Geological Survey of India, H. B. Medlicott, discussing the prospects of artesian borings in India over 70 years ago, showed that conditions are generally very different from those of the exceptional cases just quoted. He demonstrated how artesian conditions can also be brought about by the subsequent tilting of horizontal strata, or in undisturbed strata possessing a well-marked original slope of deposition, adding that 'partial artesian action is always possible when percolation along the planes of bedding is much more easy than across them'. It may also arise when inclined porous beds capable of storing and yielding water thin out, or change their lithological character, or again, meet obstructions such as pugged faults or igneous dykes, all factors to be taken into consideration by the geologist when locating sites of wells. Again, it is not uncommon to find a number of water-bearing horizons, separated by impermeable layers, in the same vertical plane. Artesian wells are independent of the immediate, local rainfall, and even a temporary fall in the water-table at their fountain-heads need not cause much loss of effective head at the wells themselves. It is also possible for the water of artesian reservoirs to escape naturally through springs or into the sea, and yet for it at the same time to provide the supplies of wells at higher locations, owing to the frictional resistance developed along the courses of the underground channels. The discharge of water from flowing wells in some parts of the world is known to be due to the compression exerted on the aquifer by the weight of its

over-lying rocks, and other instances have been described in which the flow is attributed to the pressure of included gases, which force the water to the surface in the same manner as the expanding compressed air of an air-lift pump.

Topographically and geologically, India and Pakistan fall into three major subdivisions which correspond very roughly with the three major ground-water provinces—the mountains of the north and north-west, the Indo-Gangetic plains, and the Peninsula. Burma, too, has its threefold subdivision into the coastal and deltaic tracts, the central dry basin, and the submontane and mountainous regions further north. The rainfall in all three countries, the source of all the ground and surface water, is dominated by the character of the monsoons. The south-west monsoon, lasting from June to October, feeds Burma, though the high ground of the Arakan and Pegu Yomas deprive the central 'Dry Zone' of its full amount of rain. The average fall for the whole of India during these months is about 40 inches, the actual quantities ranging from about 15 inches (or less) to over 50 inches, but there are some special areas which have a very much greater and others with a lower precipitation still. Thus part of the monsoon current is deflected into the *cul de sac* between the Assam Plateau and the Lushai Hills, giving Cherrapunji, 4,500 feet above sea level, its reputation of the wettest place on earth, with its annual 13 yards of rain. Another part blows up the Ganga valley, causing heavy falls on the Himalayan foot-hills and lighter ones on the plains until, attenuated, it meets the remains of the Arabian current about the Delhi ridge. The Western Ghats lie across the path of this Arabian current and their crests receive upwards of 300 inches yet, as far as their hinterland is concerned, 'within 30 miles of the crest of the Ghats themselves practically no place has 30 inches'. The rainfall of the cold season between December and March amounts to only 2 to 4 inches, and neither this nor the occasional storms make any noteworthy contribution to the underground stores.

The foregoing remarks apply only in a broad way to the greater part of the Indo-Gangetic plain and adjoining northern parts of the Peninsula. Further south, over the greater portion of Madras and parts of Andhra, other conditions prevail and the bulk of the rainfall is received in what is the dry, cold season in the greater part of India, from November to February. The normal rainfall over much of this southern region varies from 20 to 30 inches, but it is unusually variable and capricious in its distribution: moreover, the great arc of the Nallamallai Hills and their extensions in the Eastern Ghats generally, which are more or less parallel with the coast, raise an effective barrier against the moisture-laden winds of the main monsoon.

Taking the country as a whole, regions near the head of the Bay of Bengal and along the submontane belt as far as Jammu, as well as the Western Ghats, have an annual rainfall of more than

70 inches. The Ganga valley, parts of Orissa, Madhya Pradesh and the Madras coast receive between 30 and 75 inches. A broad and irregular belt, extending from south-western Kashmir through the Punjab, eastern Rajasthan and Madhya Bharat into the Peninsula, gets from 20 to 40 inches, a large proportion of which is winter and spring rain as far as the north-west, Lesser Himalayan zone is concerned, while the annual precipitation in a vast stretch of territory, including the greater part of Rajasthan, Western Pakistan, the Andhra-Hyderabad-Bombay border regions and Berar, is less than 20 inches. Western Rajasthan and the adjoining tracts of Sind are semi-deserts which receive but a few inches of a very uncertain rainfall, so that agriculture becomes impossible without irrigation of some kind.

Neither India nor Pakistan could maintain its present population on the existing cultivated areas were the crops entirely dependent on rainfall. 'Of the total cultivated area of 280 million acres,' wrote Sir Bryce Burt of the Council of Agricultural Research, in 1937, 'no less than 60 million acres are annually irrigated.' Of this area 30 million acres were irrigated from canals, 15 million acres from wells and 15 million acres from streams, tanks and other sources. Of the modern Indian canal systems those of Sind and the Punjab are amongst the better known. Some parts of Sind and of the south-west Punjab are practically rainless and large areas in them have literally been won from the desert and changed into arable lands. Further south-east in the Punjab, and onwards into Uttar Pradesh, the canals supplement the rainfall and at least double the yield of the winter crops. In the year 1941-2, 88 per cent of the total acreage sown in Sind was irrigated by Government irrigation works; in the Punjab as a whole and in Uttar Pradesh they spread their facilities over 39.5 and 16.8 per cent of the cultivated lands, respectively; the corresponding figures for Madras including Andhra and the North-West Frontier Province for the same year being 21.2 and 19 per cent.

Of major importance though these great irrigation canal systems are, underground water from wells also plays an indispensable part in the cultivation of some 15 million acres, or about one quarter of the total irrigated area. Tanks, according to official statistics published by the National Planning Committee on River Training and Navigation, in 1947, account for a further 5.8 million acres. While canal construction on a large scale is an undertaking which can only be financed and carried out by the agencies of the State itself, and the single tube-well is more or less an individual concern, the tank is generally a communal enterprise in the building of which a whole village community is commonly engaged. 'Its size varies from large reservoirs catching and holding billions of cubic feet of water, to be drawn upon as and when required for the service of thousands of acres of adjoining land, to a small store for the use of the immediate village, its lands and cattle.'

In spite of all that has been accomplished in both ancient and modern times, wide regions still remain wherein the rainfall is barely sufficient in normal years to support agriculture, and where, in dry years, or in others when the rains are untimely, the crops are ruined with disastrous consequences. Some years ago it was thought that artesian supplies of water might be available on a large scale, to prevent or at least ameliorate such calamities, but E. W. Vredenburg after a prolonged study of the problem in such regions, both in India and Pakistan, concluded that the supplies from artesian reservoirs can at best only be local and inadequate. He advocated the more widespread development of percolation wells to tap the ground water, adding that there are many places so situated topographically that such wells provide the only possible means of irrigation. At the present time, in order to stimulate the construction of wells and the more extended use of ground water, the Government has adopted a policy of granting advances to cultivators prepared to sink wells on their land, and of foregoing the probable increase of land revenue wherever such initiative has been shown. The large-scale construction of tube-wells under official auspices has also commenced in both India and Pakistan and is dealt with in later paragraphs.

The fact remains, however, that irrigation from canals deriving their water from the perennial flow of the river channels, or from reservoirs constructed across them, will enhance the value of the land considerably more than irrigation from wells can do. In the opinion of Professor L. W. Lyde, 'far more water is running to waste in India than is needed to make habitable all but the very driest regions, and to supply them with quantities of power for all their needs, quite apart from agricultural and sanitary operations on a large scale'. The Central Board of Irrigation estimated in 1947 that this waste of river water amounts to 94 per cent of the available flow, and added that if only one third of this unused water potential is utilizable, 'it will amount to five times the total quantity of water which is being used at present for irrigation throughout the country'.

The notes on ground-water conditions which follow are arranged according to the particular group of rocks with which they are associated, as set out in the table of principal geological formations. The geographical distribution of these is delineated on Map XI, based mainly on the work of J. B. Auden (1950). The table showing the manner of the occurrences and the methods adopted in various parts of the country for the recovery of the water (pp. 672-3) was also compiled mainly by the same author.

PRINCIPAL GEOLOGICAL FORMATIONS

- (I) Ancient crystalline and metamorphic rocks (Archaeans).
- (II) Cuddapahs and Vindhyan.
- (III) Gondwanas.

- (IV) Deccan Traps.
- (V) Mesozoic and Tertiary sedimentary rocks of extra-Peninsular India, together with their extensions in Western Pakistan and Burma, including the Plateau Limestones of the Shan States (Palaeozoic in part), made up of the following facies:
 - (1) Mesozoic and Eocene calcareous rocks.
 - (2) Higher Tertiary sandy rocks.
- (VI) Recent and sub-Recent.
 - (I) Older and Newer Indo-Gangetic alluviums.
 - (II) Deltaic alluvium.
 - (III) Lateritic rocks.
 - (IV) Desert deposits.

THE CRYSTALLINE ROCKS

The water-retaining capacity of the crystalline and metamorphic rocks which build up the greater part of Peninsular India is small and insignificant, though water may occur in their joints, fissures, fractures, foliation and bedding planes, as well as in any crush zones where they have been mechanically comminuted. In the widespread regions in which such rocks occur, ground-water supplies are in the main confined to the mantle of weathered rock which generally covers them, to a greater extent in valleys than on ridges and high ground and, as a rule, best developed beneath thick soil caps. The average depth to ground-water level varies both with the locality and with the season.

In those districts of southern India with a comparatively poor rainfall, such as Bellary and Coimbatore, the average depth of the water-table in summer is about 45 feet, though the general average for the whole of south India may be taken as approximately 27 feet in summer and 17 feet in winter. The lateral flow of ground water towards the natural drainage systems lowers the depth of the water-table in plateau regions such as Mysore.

It is hazardous to attempt to forecast the probable yield of a well dug in the decomposed mantle of the gneissic strata of southern India, but, generally speaking, a yield of 10,000 to 12,000 gallons of water per day, from a well of 20 feet diameter, would be considered good for areas such as Mysore and Hyderabad, while 3,000 to 4,000 gallons are usually available from wells in the greater part of Madras and Andhra.

In the cases of wells or boreholes, usually of 4 to 6 inches in diameter, drilled into the mantle of decomposed gneissic rocks in Madras and Andhra States, conditions vary so greatly from one district to another that no general rule applicable to all can be safely given, but in the following table, the average conditions applicable to the separate taluks of a number of districts are tabulated, based on information supplied by the Department of Industries and Commerce of the Government of Madras (1951). The records of this Department as also those of the newly created

Andhra State (1953) should be consulted for the performance of individual wells, especially before the location of new boreholes in any of the taluks in question.

AVERAGE GROUND-WATER CONDITIONS IN THE GNEISSIC DISTRICTS OF ANDHRA AND MADRAS

(G.W.L. = Ground-water level. G.P.M. = Yield in gallons per minute.)

DISTRICT	TALUK	GENERAL CONDITIONS
Kurnool	Pattikonda	G.W.L. below 12 feet: average depth of bores 50 feet: G.P.M. 4 to 10.
"	Dhone	G.W.L. between 20 and 45 feet: bores 40 to 100 feet: G.P.M. 5 to 8.
Anantapur	Gooty	Boreholes 50 to 100 feet yield 6 to 20 G.P.M.
"	Anantapur	Boreholes to 50 feet yield 5 G.P.M.
"	Kalyandrug	Boreholes to 70 feet yield 3 to 5 G.P.M.
"	Penukonda	Boreholes 50 to 120 feet yield 3 G.P.M.
North Arcot	Wandivash	G.W.L. below 10 feet: boreholes 30 to 70 feet: G.P.M. 5.
"	Gudiyatham	G.W.L. below 25 feet: boreholes 50 to 100 feet: G.P.M. 6.
"	Tiruvannamalai	G.W.L. below 10 feet: boreholes 50 to 100 feet: G.P.M. 2 to 8.
"	Vellore	Good seepage below 20 feet: boreholes 60 feet: G.P.M. 5.
Chittoor	Pungannur	Good seepage below 40 feet. Boreholes average 80 feet.
Coimbatore	Coimbatore	G.W.L. below 30 feet: boreholes 100 to 200 feet: yield 5 to 100 G.P.M.
"	Bhavani	Good seepages below 40 feet: boreholes 30 to 80 feet: G.P.M. 5 to 20.
"	Gobichettipalayam	Good seepages between 20 and 200 feet: boreholes 80 to 200 feet: G.P.M. 5 to 15.
"	Erode	G.W.L. below 30 feet: boreholes 40 to 200: G.P.M. 5 to 15.
"	Avanashi	Good seepages below 45 feet: average boreholes 90 feet: G.P.M. 5 to 25.
Ramanathapuram	Srivilliputhur	G.W.L. below 18 feet: boreholes 50 to 150 feet: G.P.M. 6.
South Arcot	Tindivanam	Good seepages below 20 feet: boreholes 40 to 150 feet: G.P.M. 4.
"	Tirukkovichur	Good seepages between 35 and 90 feet: boreholes 50 to 110 feet: G.P.M. 6.
Tiruchirapalli	Karur	Water table below 30 feet.
Tirunelveli	Tirunelveli	Water table at 15 to 20 feet: average boreholes 80 feet: G.P.M. 5 to 10.

AVERAGE GROUND-WATER CONDITIONS IN THE GNEISSIC DISTRICTS OF ANDHRA AND MADRAS—*Continued*

DISTRICT		TALUK	GENERAL CONDITIONS
Tirunelveli	..	Srivaikundam ..	Good seepages below 37 feet; boreholes 50 to 100 feet: G.P.M. 5 to 15.
Madurai	..	Palani ..	Good seepages between 12 and 58 feet; boreholes 70 to 120 feet: G.P.M. 3 to 15.
"	..	Dindigul ..	Good seepages 25 to 225 feet; boreholes 80 to 200 feet: G.P.M. 1 to 4.
"	..	Melur ..	Good seepages 20 to 106 feet; boreholes 40 to 90 feet: G.P.M. 5.
"	..	Nilakottai ..	Good seepages 20 to 80 feet; boreholes 50 feet: G.P.M. 5 to 20.
"	..	Periyakulam ..	Good seepages 20 to 110 feet; boreholes 60 feet: G.P.M. 10 to 30.
"	..	Thirumangalam ..	Good seepages between 30 and 60 feet; boreholes 40 feet: G.P.M. 4 to 12.
"	..	Madurai ..	Good seepages between 30 and 65 feet; boreholes 35 to 40 feet: G.P.M. 2 to 27.

In some parts of south India, such as Chittoor, Bellary and North Arcot, the presence of dolerite dykes and quartz veins traversing the mantle of decomposition causes a blockage of the flow of the ground-water, and by acting as dams such natural obstacles cause a rise in the water-table on the upper side of the hydraulic flow. Fresh and unjointed rock approaching or reaching the surface through areas of more profound rock decomposition also causes the same effect: for example, in the Raichur Doab and Surpur taluk of Hyderabad, the junction of the unaltered Dharwarian schists with the weathered Archaean gneisses is frequently marked by the presence of springs, though they are often of a saline character. Phenomena such as these may occur in any gneissic region and have been noted in Singhbhum, Bihar.

In other parts of south India, as for instance in the Sular *firka* of Coimbatore, the gneissic rocks often contain more than two sets of water-bearing joints, extending down to 120 feet or so from the surface, and they are frequently tapped by boreholes from the bottoms of the earlier hand-dug wells.

As a general rule the water derived from wells in the regions occupied by gneissic rocks is fairly soft and quite potable, with the exception of areas such as those of parts of Coimbatore, Madurai, Ramanathapuram and Tirunelveli, where the rainfall is scanty and the overlying soils contain abundant *kankar* and calcareous tufa at ground-water level. In such situations the water is hard and injurious to the health of those unaccustomed to drinking it.

In recent years it has been found in many parts of the world that there is a low incidence of dental caries in communities where the drinking water supplies contain a certain percentage of fluorine, so much so that controlled experiments are now being made on a large scale, both in the United Kingdom and in the United States of America, to determine whether the incidence of caries in children can be improved by artificial fluoridation of water supplies, sodium fluoride being added to the water to bring its fluorine content up to 1.0 to 1.2 parts per million. But, according to a report published by the British Ministry of Health in 1951, when the concentration of fluorine in the water exceeds about 1.5 parts per million, mottling of the teeth, the first symptom of fluorosis, becomes increasingly apparent. With a concentration of 5 parts per million the teeth become seriously disfigured and with still higher amounts toxic symptoms and bone lesions may occur. Thus while a concentration of 1.0 to 1.2 parts per million provides a considerable reduction in caries without appreciable mottlings higher concentrations may be very harmful.

In the northern parts of the Nellore district, the occurrence of mottled teeth and other affections amongst the populace is due to the presence of fluorides in the ground waters, according to H. E. Shortt, C. G. Pandit and T. N. S. Raghavachari. The occurrence of fluorides in the ground waters of various localities from Visakhapatnam in the north to Tirunelveli in the south, and from Chingleput in the east to Coimbatore in the west, has been investigated by T. N. S. Raghavachari and K. Venkataramanan, and they have recorded fluorides in excess of 3 parts per million in the Podili, Darsi and Kanigiri taluks of Nellore, as well as in isolated places in Anantapur, Bellary, Kurnool, Cuddapah, Guntur, Visakhapatnam, North Arcot, Salem and Coimbatore districts. The highest fluoride incidence is 'in the narrow belt of granitoid rocks stretching north-north-east from south of Kanigiri, in Nellore district, to the Kistna river near Amavaravathi, in Guntur district'. The fluorine is doubtless derived from fluorite-bearing rocks in the main mass of the gneisses. Specimens of rocks from the highly affected areas were found to be rich in fluorite and fluorapatite.

THE CUDDAPAH AND VINDHYAN ROCKS

The calcareous and argillaceous rocks, underlain by predominantly sandy types, which form the great Cuddapah and Vindhyan Systems, are developed in force in the Cuddapah and Kurnool districts of Andhra, in parts of the Bijapur district of Bombay, in the Raipur-Bilaspur-Raigarh region of Madhya Pradesh and in parts of central India and Uttar Pradesh. The slates, shales and limestones of these formations are not good water-yielders; their fine-grained sandstones are of low porosity, but where coarse-grained and conglomeratic they may carry small supplies of water.

In both Cuddapah and Kurnool districts, the quartzites, limestones and shales are generally sufficiently well jointed near the surface to provide small supplies for domestic purposes, the water table lying at a depth of 25 to 40 feet in most cases, but the step wells and tanks are liable to be infected by guinea worm. Similar conditions prevail in Bombay (Bijapur district) and in those parts of Hyderabad into which these rocks extend, but the ground-water level is deeper, usually below 50 or 60 feet in Bijapur. Some of the areas covered by the formations, such as the Chhattisgarh Basin (the Raipur-Bilaspur-Raigarh area of Madhya Pradesh) appear suitable from a structural point of view for artesian water supplies, but unfortunately the rocks themselves are not suitable storage containers, and draw-wells to tap the subsoil water seem likely to remain the sole source of supply.

AVERAGE GROUND-WATER CONDITIONS IN THE CUDDAPAH AND KURNOOL (VINDHYAN) ROCKS OF ANDHRA STATE

DISTRICT	TALUK	GENERAL CONDITIONS
1. Kurnool ..	Cumbum ..	Water level below 15 feet; boreholes 60 to 100 feet; yield 5 G.P.M.
2. Cuddapah	Pulivendla	Seepages below 25 feet; average boreholes 70 feet; yield 5 G.P.M.
3. ..	Prodattur ..	Better seepages between 25 and 75 feet; boreholes 50 feet; yield 5-10 G.P.M.
4. Anantapur	Tadpatri	Average boreholes 100 feet in depth; yield 6 G.P.M.
5. Kurnool ..	Sirvel ..	Better seepages between 30 and 37 feet; boreholes 60 to 100 feet; yield 5 G.P.M.
6. ..	Koilkuntla ..	Better seepages between 20 and 100 feet; boreholes 60 to 120 feet; yield 7 G.P.M.
7. Cuddapah	Jammalamadugu	Better seepages between 20 and 50 feet; boreholes 80 feet; yield 5-15 G.P.M.
8. ..	Cuddapah ..	Better seepages between 21 and 125 feet; boreholes 50 to 100 feet; yield 5 to 20 G.P.M.

Nos. 1 to 4 refer to 4 or 6 inch holes in Cuddapah slates, limestones, quartzites, etc.
 Nos. 5 to 8 refer to 4 or 6 inch holes in Kurnool shales, flags, limestones, etc.
 G.P.M. = gallons per minute.

In the Maihar and Satna areas of central India, the Vindhyan limestones north of the Kaimur Range are sufficiently jointed to yield household supplies of potable water from wells 15 to 25 feet deep, but in those parts of Maihar and Jabalpur south of the Kaimur Range, similar wells occasionally dry up in the summer. North of the Son river, in the Mirzapur district of Uttar Pradesh, the wells in the Vindhyan sandstones, shales and limestones are, as a rule, up to 35 feet in depth and yield fair supplies, though they are locally brackish and unfit for drinking. South of the Jamuna

river, in places like Khiri and Sanaori, in Allahabad district, the average depth of the wells is about 60 feet, with the water level at 25 feet and 20 feet below ground level, before and after the rainy season, respectively.

Data regarding drilled wells in the Cuddapah and Kurnool (Vindhyan) rocks, kindly supplied by the Industries and Commerce Department of Madras State in 1951, are summarized in the foregoing table.

THE GONDWANAS AND CERTAIN OTHER MESOZOIC AND TERTIARY SEDIMENTARY ROCKS

The leading rock types of the Gondwana System are sandstones and shales as well as smaller thicknesses of conglomerates. The water-bearing and water-yielding capacities of these types vary greatly with changes in their storage capacity, permeability and imbibition, but generally it is fairly safe to assume that the sandstones, and especially the soft, porous varieties, are more or less saturated and capable of supplying good quantities of water from borings or from large-diameter wells.

A great part of southern Bihar, Western Bengal, the Mahanadi basin, and the Pranhita-Wardha-Godavari valley, is covered by Gondwana rocks, as also are certain regions in Madhya Pradesh, such as those around Satpura and in the Kanhan and Pench river valleys. Such rocks are to be found again in parts of the West Godavari and Ramanathapuram districts of Andhra and Madras respectively, where water under sub-artesian conditions has been tapped. A single tube-well, for example, 100 feet deep, at Karaikudi, in Ramanathapuram, from which water is pumped at the rate of 100 gallons per minute, meets the requirements of this particular town. Another borehole in this vicinity has been recently drilled to a depth of 400 feet and in it the water level rises to 60 feet below the surface; its yield is said to be 15 gallons per minute.

In the West Godavari district, Gondwana sandstones holding their water under artesian conditions are known to occur at Borrampalam, Yerragudem and other places; moreover, there is an artesian basin in the Tertiary sandstones which extend from Bhimadole to Badampudi and thence curve around towards Madhavaram. In the East Godavari district, again, there is another artesian basin in similar Tertiary sandstones which extend from Rajahmundry to Samalkot: thus, artesian conditions are said to exist over the areas of Medapudu, Dwarapudi, Vempalle and Anaparthi, where the wells are located close to the boundary between the Rajahmundry sandstones and the alluvium. They are tube-wells from 200 to 400 feet in depth and the best supplies are obtained from below 300 feet, the average yield from a 4-inch hole being 80 gallons of artesian water per minute. It is to be noted that

artesian conditions also prevail at Gadala through which the boundary between the Rajahmundry sandstone and the Deccan Trap passes. As examples of the ordinary type of tube-well, as distinct from the artesian and sub-artesian ones just described, 4-inch holes drilled to depths of 100 to 200 feet in Gondwana sandstones, in the Nuzvid taluk of the Krishna district, may yield anything from 6 to 80 gallons per minute, the better aquifers being found below a depth of 23 feet. In the Bhadrachalam taluk of East Godavari, 6-inch holes drilled to a depth of 60 feet yield about 5 gallons per minute, the water-bearing zones occurring below a depth of 18 feet. Details of these and other artesian wells are given in the table on p. 674.

Parts of the Tiruchirapalli, the East and West Godavari districts and the strip of country in southern Madras extending from Pondicherry to Uttattur are covered by a series of limestones, sandstones and clays of Mesozoic age, from which shallow wells provide adequate supplies for domestic requirements. In the coastal region between Cuddalore and Pondicherry, as well as in the area between Cuddalore and Vriddhachalam, water under artesian conditions is known to exist in the Cuddalore Sandstones of Tertiary age. It is usually met with at depths of from 150 to 500 feet below the surface and the yield may vary between 20 and 1,000 gallons per minute. From the Warkalli rocks of similar age and types, in Travancore, fresh water is obtainable from below depths of 70 to 130 feet.

In Madhya Bharat, the sandstone horizons of the Lameta and Bagh Beds yield copious water within a depth of 30 feet according to M. K. Roy Chowdhury. The yield is sometimes more than 1000 gallons per hour for some hours.

Turning now to western India, as far as is known, while the Mesozoic sandstones of western Kutch generally yield good supplies of water, the Tertiary formations of the west and south-west contain barren areas. In eastern Kutch, supplies are abundant from the Bhuj Series of Cretaceous age: in it there are several water-bearing horizons from the outcrops of which supplies are often obtainable under sub-artesian conditions. A well at Viri, 15 miles west of Kandla, 200 feet deep, is stated to yield 42,000 gallons per hour after development by gravel packing. Irrigation by wells deepened by means of boreholes taken down to between 80 and 130 feet is common in Anjar, Nagalpur, Khedoi and Dudhai. On Patcham Island, the Jurassic limestones do not yield potable water though it is obtainable from wells, about 50 feet deep, sunk in widely separated locations, on Tertiary rocks, alluvium and laterite. In contrast to this, further south at Morvi, in Saurashtra, the Jurassic rocks contain three separate water-bearing horizons, according to B. C. Roy: the first of these is close to the surface, the second at a depth of about 200 feet and the third at 500 feet approximately. Between Dhrangadhra and Halvad copious potable supplies are

available at depths ranging roughly from 100 to 500 feet. Although trial borings in the Wadhwan only obtained brackish water at a depth of 648 feet, another, in search of coal at Khakrathal, encountered potable artesian supplies of 1,500 gallons per hour at a depth of only 65 feet. At Kharaghoda abundant artesian water, amounting to a flow of the order of 6,000 gallons per minute, comes from an 8-inch borehole carried down to 317 feet. Similar conditions prevail at Udoo at a depth of 273 feet. In the coastal tracts of Saurashtra, wells in the Gaj Beds usually yield good potable supplies within 20 to 35 feet of the surface though the wells in Bhavnagar are sometimes saline. Drinkable water is occasionally available along the junction of the Gaj Beds with the overlying Trap rocks. The shelly limestones and sandstones of the Dwarka Beds are said to have yielded some water from a borehole 390 feet deep at Adatra (Okha port).

Calcareous rocks of the Mesozoic period are well developed in Baluchistan and in Kashmir, though in both regions supplies are not usually obtainable from the limestones but from those unconsolidated gravels and talus deposits, known collectively as Daman Slopes and Karewas, respectively. In Baluchistan, particularly in the Quetta region, these loose, sedimentary formations yield water under artesian pressure, when overlain by more or less impermeable, fine-grained deposits of loess. Water is also obtained locally by means of long, underground channels, known as *karezes*, which are driven into the loose material filling most of the valleys and their lower slopes. In some parts of Baluchistan water is also obtained by sinking wells through the shingle of dry stream-courses subject to spates, into the decomposed upper surfaces of the underlying bed-rocks. In the case of Kashmir the upper boulder and gravel beds of the Karewa formation have proved to be good water-yielders.

THE DECCAN TRAP

A great part of the western half of Madhya Pradesh, practically the whole of Bombay State and of the Saurashtra peninsula, parts of Kutch and nearly half of Hyderabad, as well as small portions of the East and West Godavari districts of Andhra, are covered by the thick, bedded, lava flows of the Deccan volcanic period: furthermore, similar trap rocks also occur in the Rajmahal Hills of Bihar. The flows themselves are of both vesicular and non-vesicular types, generally massive and well jointed, usually horizontal but possessing low dips in some areas. Successive flows are sometimes separated by thin beds of volcanic ash, and, more rarely, by sedimentary rocks known to Indian geologists as 'inter-Trappeans', and in many places they are capped by lateritic formations of varying thickness. As a general rule the Deccan Traps are thoroughly unreliable sources of ground water because of their inherent composition, structure, texture and the sporadic distribution of

their inter-Trappean beds; borings for water in them have been uniformly disappointing and can only be justified as a forlorn hope in the absence of any other possible source of water supply. A boring put down at Daryapur, in Berar, for instance, after passing through 320 feet of alluvium, with nodular, calcareous clays, penetrated no less than 1,053 feet of Deccan Trap lavas and associated ash beds, without meeting any appreciable quantity of water. Exceptional situations do of course exist here and there in the vast areas covered by these volcanic rocks, thus three boreholes recently put down at Borivli, near Bombay, happen to have struck a spongy chloritic tuff which yields fairly large quantities of water of good quality under sub-artesian conditions from depths of 240, 264 and 293 feet. The yield from the first of these is stated to be 14,000 gallons per hour from a 6-inch hole. Near Belgaum, in Bombay, the trap is thin and the flows happen to rest upon loose sandstones and pebble beds of the Lameta formation, so that the water prospects are more hopeful. Otherwise, supplies are derived from the softer surface deposits, as in some of the trap areas of Saurashtra, where wells sunk for 15 or 20 feet into the weathered material are sufficient for domestic needs. In Saurashtra, generally speaking, porous inter-Trappean beds are rather rare and wells on narrow hill tops, both in this region and elsewhere, are not likely to be successful owing to their limited storage areas and their exhaustion by natural springs on the hillsides. Even on the tops of extensive plateaus, where water may be preserved in the laterite cappings, or in the beds of *moorum* and boulders (weathered products of the trap itself), supplies are often exhausted in the dry season by leakage through springs on the lower slopes at the junction of the aquifers with the underlying fresh and impermeable rock. Shallow wells located on the banks of streams, or at the junction of stream-courses, usually give fair supplies for household purposes, and in Saurashtra, where trap dykes are common, they occasionally cut across the dry beds of streams and so create storage reservoirs of limited extent. As a rule, the water from the Deccan Trap is hard, especially if drawn from the decomposed, amygdaloidal varieties of the formation, while the subsoil water is often brackish owing to the presence of sodium chloride and the sulphates of calcium and magnesium.

HIGHER TERTIARY SANDY ROCKS

As examples of these the underground waters of Chittagong, the artesian and sub-artesian wells of some parts of Andhra and Madras, the conditions prevailing in the Potwar plateau of the West Punjab and in the Central Basin of Burma are taken. The water supply of Chittagong, in Eastern Pakistan, is derived from Tertiary rocks which crop out in a ridge of low hills lying to the south-west of the town. It is under sub-artesian conditions, as the

effective head, owing to the low elevation of the outcrop, is not sufficient to force the water to the top of the boreholes. The first of these, located by Sir Henry Hayden in 1906, was 700 feet deep and encountered water-bearing horizons, 10, 40 and 92 feet thick, at 165, 215 and 235 feet from the surface, respectively. The highest and lowest aquifers were shut off and the water from the 215-foot water sand then rose to within 8 feet of the surface, with a constant yield of 1,100 gallons per hour from a $3\frac{3}{4}$ inch bore. Two later tube-wells 428 and 442 feet deep, of 6 inches diameter, each gave between 13 and 14 thousand gallons per hour. Chittagong has an annual rainfall of over 100 inches.

Some of the flowing wells of the coastal districts of Andhra and Madras, mentioned in the section dealing with Deltaic and Coastal Supplies, derive their water from the Guddalore and related sandstones of Upper Tertiary age.

The Potwar plateau, lying between the northern slope of the Salt Range and the Sohan river, is partly covered with alluvial deposits and loess, and in other parts is a rock-strewn plain from which isolated ranges of low hills and thin, narrow ridges of Siwalik age project. The rainfall is usually less than 20 inches yearly, the alluvium has a high porosity and the water-table lies deep, in places over 200 or 300 feet below the surface. As a result the wells are deep and fitful in yield and it is not uncommonly saline or alkaline in nature. Wells in the loess, or in the alluvial caps, almost invariably give poor yields unless they penetrate into some underlying Siwalik horizon, but those placed on the Siwaliks themselves have better chances of drawing on perennial supplies. 'Dug wells of the usual percolation type, even of large diameter,' writes Dr D. N. Wadia, 'will not solve the water difficulties of the Potwar. The great annual expenditure of money in digging new wells is in a large measure unremunerative, but with the same outlay if new tube-wells were sunk in the alluvial tracts, or tubes of 3 to 4 inches diameter were drilled in the bottoms of existing wells up to depths of 60 to 100 feet, the results would do more towards meeting the domestic needs of the people and of enhancing the area of well-irrigation. A given number of tube-wells of say 3 to 4 inches diameter and of 200 to 300 feet in depth, provided with any suitable type of strainers, would tap the underground water reservoirs far more efficiently and economically than double their number of the existing type of percolation wells.'

The central basin of Burma, extending from the Thayetmyo district in the south to the Shwebo district in the north, is often referred to as the Dry Zone. Its annual rainfall is usually between 15 and 30 inches, though to the south the Irrawaddy delta averages 90 to 100 inches, while the submontane districts further north receive between 70 and 100 inches. For the most part it is built of gently rolling uplands of Irrawaddy sandstones often covered by Plateau Gravels and pierced in places by inliers of rocks of the Pegu

System. The soft sandy strata of both are intricately dissected by tortuous, branching, deeply cut nullahs. During the dry season, when the percolation wells and village tanks become dry, water is to be found only in the very largest of the streambeds, such as the Pin Chaung, the Yaw river and the Mon Chaung, the great majority of the smaller ones being choked with sand and boulders. By digging a few feet into their beds, however, it is often possible to obtain water though it is apt to be saline, especially near the Pegu exposures. Each of the thirteen districts of the Dry Zone, in spite of the fact that the Irrawaddy flows through most of them, possesses its 'waterless tracts' which become more or less desiccated in the dry season with corresponding hardship to man and beast. Anxious consideration has been given to the problem of underground water supplies in such areas, the conclusions reached being available in the Annual Reports of the Geological Survey of India, but the prospects are almost universally poor, though certain sites have been recommended for experimental borings. The late Sir Edwin Pascoe had an intimate, personal knowledge of the Dry Zone and summarized his opinion as follows: 'As in all cases on rocks of the Pegu and Irrawaddian series the water supply question in the Meiktila, Myingyan and Pakokku districts, presents insuperable difficulties. No satisfactory scheme is possible for providing a really adequate water supply from tube-wells owing to the underground water being charged with magnesium and sodium salts. Where the alluvium is thick, and the thickness can only be surmised at best, shallow tube-wells may give a fairly good supply but the location of such wells can only be arrived at by a process of trial and error. In the jungle, sweet and potable water can generally be obtained from wells sunk in the alluvium of river valleys or from wells sunk at the lower end of a stretch of paddy fields. This the local inhabitants are generally aware of. Deep borings are useless as the water of both the Pegu and Passage Beds and also of the Irrawaddian is frequently saline and sulphatic. On the more shaly Pegu rocks open tanks sometimes provide the village supply, wells being sunk where possible in the low ground below the outlet end, the *band* then acting as a filter, but as this is only run-off water, it cannot be relied on to any great extent. The same conditions apply to the whole of the dry zone of Upper Burma, and the only aid the geologist can give is to point out areas covered by alluvium and enjoin the local inhabitants to make shift as best they can, the relatively lowest ground being first essayed.'

Such hand-dug wells in the alluvium of flood plains and stream-beds yield potable water for domestic purposes in Thayetmyo, Minbu, Pakokku, the Lower Chindwin and Mandalay districts, and in Monywa, the chief town of the Lower Chindwin, infiltration galleries have met with a certain measure of success. Near the Irrawaddy good water is often obtainable. Thus in Mandalay tube-wells yield supplies from depths of 100 to 300 feet;

at Magwe at about 100 feet; at Nyaunghla between 150 and 300 feet and at Paungdaw, two miles west of the Twingon section of the Yenangyaung oilfield, between 162 and 186 feet in one well and between 144 and 278 feet in another. These and other examples prove that abundant supplies of potable water exist both in alluvium and Irrawaddian rocks, derived by seepage from the river itself, but to what extent these particular sources extend east and west of it still remains to be determined. Water under true artesian conditions underlies the plain of Taungdwingyi in the Magwe district. The town itself lies on alluvium though quite close to a band of Irrawaddian rocks, soon followed by the chief Pegu outcrops of the Yoma, which rise to a maximum height of 1,600 feet. Three tube-wells of 6 inches diameter were sunk in 1917; two of them draw their supplies from a gravel between 79 and 80 feet below the surface, the third from a similar source at 102 to 120 feet. The first two wells overflowed at a rate of 2,000 gallons per hour and the third at 88 gallons. Supplies are probably gathered on the high ground of the Pegu Yoma to the east and, unable to enter the comparatively impervious Pegu rocks hereabouts, flow down along their junction with the Irrawaddian to be stored in them and in the alluvium below the plain.

THE INDO-GANGETIC ALLUVIUM

The Indo-Gangetic alluvium stretches across India and Pakistan from East Bengal to Karachi and it is best divided into two basins: Ganga-Punjab and Indus, which gravity observations seem to indicate are separated in depth by underground extensions of the Aravalli Range. The Ganga-Punjab basin extends from West Punjab to East Bengal, crossing Uttar Pradesh where, owing to the tectonic downwarp in front of the Himalayas, the alluvium probably attains its maximum depth of about 10,000 feet near Roorkee (Gulatee, 1952), while in northern Bihar it may be more than 6,000 feet. In this basin much of the water of the submontane streams soaks down into the gravels, shingles, coarse sands and talus deposits of the *bhabar* zone along the foot-hills, to emerge again in the form of springs along the borders of the *tarai*, giving rise to its prevailing marshy character. In the plains adjoining the *tarai* the underground water is often under considerable pressure and there are numerous artesian wells, some with copious flows. Farther to the south the gravels pass laterally into sands with subordinate clays; the materials becoming finer as the distance from the hills increases, but there is a narrow belt of coarser grades again along the whole length of the fringe of the Peninsula proper. On the plains the ground water is usually within 40 feet of the surface. In the western parts of Uttar Pradesh it is extensively drawn upon for irrigation purposes, and there are more than 2,000 tube-wells with an average depth of about 300 feet and an average yield of

about one cubic foot per second. To the south and west of Delhi and to the west of Agra, brine is found locally in wells dug in the alluvium. The salt may be derived from springs in the rock below the alluvium. In Bihar, coarse sands near the surface occur only in certain areas, mainly in the Purnea district. There is also some evidence that at depths below 200 feet the ground water is under sub-artesian conditions, for J. A. Dunn writes that 'during and for some hours following the 1934 earthquake, water gushed out at the surface, over a wide area of country, in many cases to a height of several feet'.

Great developments are already in progress to utilize on a larger scale the subterranean water of the Indo-Gangetic alluvium for purposes of irrigation. Under the Indo-American Technical Co-operation Programme of 1952, about 2,000 tube-wells will be sunk within the next two years in parts of the States of Bihar, Uttar Pradesh, the Patiala and Eastern Punjab States Union and the East Punjab, which with their Diesel power plants and auxiliary equipment are estimated to cost about Rs 10.94 crores of which the United States contribution will be 13,700,000 dollars (about Rs 6.50 crores) and that of the Government of India, Rs 4.44 crores. Contracts have been given to an American, a German and a British firm, and the States of Uttar Pradesh, Bihar and East Punjab will drill about one-fourth of the wells with their own equipment. In the East Punjab, out of a total allocation of 355 wells, 140 will be sunk in Samrala, 75 in Panipat-Ganaur, 85 in Sonapat and 55 in Pipli. In the Patiala and Eastern Punjab States Union, 300 tube-wells will be constructed in Dhuri. In Uttar Pradesh it is proposed to sink 995 wells in the alluvial plains of the Ganga valley at various sites in Basti, Gorakhpur-Deoria, Faizabad-Sultanpur and Mainpuri. Of a total of 350 wells assigned to Bihar, 150 will be in Samastipur and 100 in Arrah-Buxar, the remainder being equally divided between Bihar-Shariff and Bihta. Supplies of drilling equipment and pipes took so much time that the operations were not in full swing until late in 1953. However, by the end of June 1954, 973 of the grand total of 2,000 tube-wells provided for under this particular project had been actually completed. In the meantime, the States of East Punjab, Uttar Pradesh and Bihar have launched their own tube-well irrigation projects, commissioning the Associated Tube Wells Ltd, of the Brush Aboe Group of Companies, England. In Bihar, the sinking of 300 wells is already in progress in various parts of Champaran, Saran, Muzaffarpur and Darbhanga in the reserved areas of sugar factories. In Uttar Pradesh, work on 440 wells is in progress at various sites in Saharanpur, Muzaffarnagar, Lakhimpur, Kheri, Sitapur, Gonda and Faizabad, while 209 are under construction in the Ambala, Karnal and Rohtak districts of East Punjab and 16 in the Patiala and Eastern Punjab States Union. Of these 965 tube-wells, each with its pumping equipment, 941 had been completed

by April 1954. They are expected to provide irrigation for some 400,000 acres. Yet another series of tube-wells, amounting in this case to a total of 650, for various parts of Uttar Pradesh, Bihar, East Punjab and the Patiala and Eastern Punjab States Union were provided for under the Indo-United States Technical Assistance Programme for 1953. The construction of 485 of these has been entrusted to a combine of French contractors and the remaining 165 are to be drilled departmentally by the Governments of Uttar Pradesh and Bihar. It is anticipated that these wells will be in operation by October 1955.

The tube-well programme thus briefly outlined is more or less confined to the proved areas of the Gangetic alluvium. To discover the ground water possibilities in other areas an exploratory project was set up in 1953 for drilling 350 wells in 16 areas selected by the Geological Survey of India. These areas include the Purna basin of Madhya Pradesh, the Tapi (Tapti) and Narmada (Narbada) valleys of Bombay and other sites in Kutch, Saurashtra, Travancore-Cochin, Madras, Orissa, Assam, West Bengal and Rajasthan, as well as unproved regions in East Punjab, PEPSU, Uttar Pradesh and Bihar. The project contemplates bringing 'stable sources of irrigation water supply in areas which suffer from chronic scarcity of rainfall and have no other source of irrigation water'. The cost of the work is to be borne by the Indo-American Technical Assistance Programme and by the Government of India. The drilling equipment will come from the United States and an American firm will provide consultant services and technical personnel. For the drilling of 3,000 tube-wells under the Indo-American Technical Co-operation Scheme including 350 exploratory ones, the total commitment up to the end of June 1954 has been \$19,530,000 for the United States and Rs 9,15,00,000 for India. The State of Bombay has undertaken the construction of about 400 tube-wells in Ahmedabad, Kaira and other districts.

The Amritsar-Ludhiana trough of the Punjab alluvium, a trough which may be about 4,000 feet deep, is demarcated on the south-west by the Delhi-Shahpur ridge. This submerged ridge has caused the building up of the ground water of the Punjab and may be responsible for the waterlogged conditions in the extensively irrigated Punjab plains, of both India and West Pakistan. In many parts of the Punjab the water is saline and this is especially the case near the Salt Range for obvious reasons. In such regions there appears to be little improvement in the quality of the water with depth, but in other parts of the Punjab, as in the Isa Khel *tahsil* of the Mianwali district, there is a definite but slow improvement as the depth increases. The Indus basin lies to the south-west of the hidden Delhi-Shahpur ridge, forming a trough in front of the mountain ranges of Baluchistan.

According to B. G. Deshpandé, in the alluvial tracts of Gujerat, potable ground water is found between 30 and 90 feet below the

surface, sub-artesian water occurs at depths of from 80 to 200 feet, while artesian supplies, usually unpotable but often suitable for irrigation, are met with in three zones between 300 and 1,200 feet in depth. The yield from the subsoil sources is generally less than 400 gallons an hour, the maximum being of the order of 8,000 gallons; from the sub-artesian zone, 1,000 to 5,000 gallons, and from the artesian sands, about 4,000 gallons per hour, though there are local exceptions to these quantities. In the alluvial tracts of north-east Saurashtra ground water occurs under much the same conditions as in Gujerat. A bored well at Viramgam has yielded 200 gallons per minute for a number of years from a depth of 770 feet below the surface, while at Gedia another borehole gives 240 gallons a minute from a depth of 270 feet.

The ground water of western Rajasthan, according to J. B. Auden, is to be found in appreciable quantities only in alluvial deposits and sand dunes, in the sandstones of the Jaisalmer and Barmer formations, in the Eocene strata and in the joints and bedding planes of the Vindhyan and other rocks. The greater part of the region is covered by alluvium and wind-blown sands, the former varying in thickness and occurring mainly along the channels of the Luni river and its tributaries. The rainfall is very small, from 5 to 15 inches annually, and much of it is lost by evaporation. The depth of the water-table, except in the Luni river basin, is generally over 100 feet and in places nearer 400 feet: in the Palana lignite field it is 326 feet below the surface of the ground and around Jaisalmer about 236 feet on an average. A well sunk recently in the bed of the Luni, near Samdari, yielded 40,000 gallons per hour, and was the cause of over-optimistic valuation of the ground-water possibilities of western Rajasthan, for when two further wells were bored on the left bank of the river, to the south of this particular well, they yielded but 200 gallons per hour. The truth is that the distribution of the water is capricious, and, further, all accounts indicate that where present, it is of a brackish character over wide areas of western Rajasthan. Taking Rajasthan as a whole, the areas where ground water occurs at a shallow depth include the Pali region of Jodhpur, the Aravalli Range and the plains bordering it, and the plains of Mewar, Jaipur and Tonk. In his Introductory Report on the 'Ground Water Resources of Rajasthan', 1950, Auden has concluded that if the former surface drainage courses, which lie buried under thick covers of blown sand, can be mapped by geophysical means, they are likely to be of importance as sources of ground water, provided it lies within reasonable depths and is sufficiently free from deleterious soluble salts. The water supply of Ajmer city is derived from wells sunk in the wind-blown sands of the Pushkar area. The wells, according to A. K. Roy, are 40 to 45 feet deep and the yield from each well averages 5,000 gallons per hour.

DELTAIC AND COASTAL SUPPLIES

The subsoil water level in Calcutta, as in most places within the deltaic regions of the Ganga and Brahmaputra, is usually from 12 to 18 feet below ground level, though at such shallow depths it is liable to be bacteriologically infected. Good water-bearing strata are not available in Calcutta or its environs above a depth of 200 feet, though generally the tube-wells are taken to much greater depths, sometimes to 750 feet in Calcutta and its suburb of Howrah, whereas in Patna and Muzaffarpur, drinking supplies are obtainable within 100 feet, though these places of course do not lie on the delta. Generally speaking, the tube-well waters of Calcutta exhibit a decrease in their content of chlorides as the distance of their locations from the Hooghly river increases, and this is particularly evident on the Howrah side of the river. The yield and the quality of the water is variable and some wells have given hard water only. N. C. Bose, in 1940, divided the ground waters of the Calcutta district into the four following zones:

(1) From Dum Dum northwards, in which the water contains a variable content of sodium chloride but is free from sulphates and chlorides of the alkaline earths.

(2) Between Dum Dum and the Lower Circular Road, wherein, although the salinity of the water increases with the age of the well, it contains no real alkalinity due to the presence of sodium carbonate.

(3) South Calcutta, where the tube-well water is more or less alkaline but without salinity.

(4) Metiaburuz and Budge Budge, in which the supplies are generally brackish.

The deepest tube-well of the whole area is that of the Garden Reach Municipality, at Akra Road, with a depth of 1,306 feet traversing silts, clays and sands. The sands are usually water-bearing and free-yielding so that large volumes of water can be pumped without any appreciable lowering of the water-table, though in quality it is generally hard and from some of the sands of a brackish character with ferruginous and other impurities, but the supplies from the 600 to 700-foot sands are of better quality. It is the opinion of Dr A. L. Coulson that all the supplies of good water from Calcutta tube-wells are derived by percolation from the Ganga and Brahmaputra rivers which lie more than 100 miles to the north, the rate of percolation being probably a mile or so annually. Constant sinking of tube-wells in and around Calcutta, without some official control of their locations, may eventually lead to deterioration in the quality of their water, as has already happened in some parts of Rangoon. Sir Cyril Fox also thought that there was danger of subsidence if the water-bearing sands below 500 feet were exhausted by widespread drilling.

Proceeding down the East Coast there are deltaic areas in Cuttack, Orissa, and in the East and West Godavari, Krishna,

South Arcot with Pondicherry, Tanjore, Ramanathapuram and Tirunelveli districts, where water-bearing sands give copious supplies, sometimes under artesian conditions. Examples of these are to be found around Neyveli, Aziznagar and Kavanaur, near Vriddhachalam in South Arcot, where there are numerous flowing wells; in and around Pondicherry; near Bhimadolu in West Godavari; Tiruturaipundi in Tanjore and in parts of Pudukkottai and Ramanathapuram. Technical details of some of these artesian wells are given on p. 674. At Visakhapatnam in Andhra the water-table is very variable and usually lies between 15 and 85 feet below surface level.

In the littoral districts, limited supplies of sweet water are usually obtainable from shallow surface wells in areas close to the beaches. In the coastal region of Balasore, potable water is obtained from shallow wells north of the Orissa Canal, but between Balasore and Cuttack, states G. C. Chatterji, there exists a lens-shaped basin, with its maximum width in the Kendrapara subdivision, in which the water is saline. Within this area temporary supplies are obtained from superficial deposits, 15 to 20 feet thick, overlying a clayey bed containing intercalations of dark, sandy material, though some of the wells yield ferruginous water from the upper strata. On the coasts of Cuttack, Puri, Ganjam and other districts further south, where blown sand has been accumulated into dunes on a large scale, it is often possible to obtain good supplies of sweet water from wells sunk into their bases, as they usually contain thin layers of impervious material which assist in underground storage under semi-artesian conditions.

Between Dhanushkodi and Tiruchendur in Tirunelveli district, shallow diggings of the character of 'soaks', 3 to 6 feet in depth, within a few feet of the beach, yield slightly brackish but drinkable water, but in periods of drought such supplies are seriously reduced. In some places, such as Kayalpattanam, near Tiruchendur, the shallow diggings on the foreshore only yield for a few weeks, so that new ones have to be made in other locations almost continuously. Similar methods are adopted in Travancore-Cochin and other parts of the West Coast. At Chavara, in Quilon, and elsewhere in Travancore, the shallow, surface hollows, left after the removal of the ilmenite sands which are exploited locally, not only supply drinking water but also meet the needs of small-scale irrigation to some extent. Larger amounts of fresh water are obtained in both eastern and western coastal districts from percolation wells dug in wet lands, or on the banks of streams and canals, or, again, near the *bands* of tanks. At Alleppey, in Travancore, such sources have been replaced to a great extent by two tubewells of 8 inches diameter, which obtain sub-artesian water from two sandy horizons, each about 20 feet thick, and separated by about 60 feet of clay, at depths of 240 and 325 feet respectively, and are pumped at the rate of 15,000 to 18,000 gallons per hour.

Another tube-well in similar alluvial strata at Thottapalli yields drinking water of a chalybeatic type, though it passes through a peaty soil charged with sulphates in its upper section. On the southernmost tip of India, at Cape Comorin, where the rocks are gneisses and charnockites, it is interesting to observe that the water-table is about 63 feet below surface level at the Rest House and probably about 20 feet at the Temple. In parts of the Andaman and Nicobar Islands, according to Dr E. R. Gee, shallow wells, 10 to 15 feet deep, sunk in recent coral rock, often at quite short distances from the shore, yield sweet water, the natural flow of which from inland sources is apparently held back by the denser water of the sea.

The recent, coastal alluvium in the vicinity of Madras city varies from about 60 to 110 feet in thickness and the ground water, nearest to the surface, appears to be confined to a sandy stratum, up to 35 feet or more in thickness, the water-table of which usually lies between 4 and 15 feet of the surface. Hand-dug wells, seldom over 20 feet deep, and shallow tube-wells sunk to a depth of 25 feet or so, yield, with a few exceptions, water which is unfit for drinking. Shallow wells, excavated to a depth of 8 feet or so on the foreshore are also used for domestic supplies. Deeper tube-wells, usually about 54 feet in depth, however, yield potable water. Tube-wells sunk to bed rock at Perambur obtained only poor quality water, but better supplies are obtained from a depth of about 70 feet, the water-table here lying between 40 and 60 feet.

The water supply of Karachi city is obtained from dry stone galleries which extend for more than a mile upstream under the bed of the Mahir river, itself dry for the greater part of the year. It is thought that deep tube-wells in this region are likely to tap connate, saline water in the Tertiary rocks underlying the alluvium.

LATERITE AND OTHER SURFACE DEPOSITS

Laterite occurs as a porous and permeable capping on the flat-topped hills of southern Bihar, Orissa, Madhya Pradesh, Hyderabad, the Eastern and Western Ghats, along the east and west coasts, along the western border of Bengal and elsewhere; as far as its storage capacity is concerned it is believed to correspond more or less to that of the well-weathered crusts of granitic and gneissose rocks. This means that under favourable conditions it is capable of holding fair quantities of water; indeed, perennial springs on the hillsides often mark its boundaries with the underlying impermeable rocks. It is for this reason that wells on narrow, laterite-covered hill tops are inadvisable, for they are not likely to be successful, though elsewhere they may obtain supplies at depths of 20 to 60 feet. Surface springs occur in many localities where the water-table is intercepted by an abrupt fall of the topographical level, as, for instance, on the eastern flank of the lateritic uplands, south-west

of Salboni railway station, and at the eastern termination of the laterite-covered uplands north-west of Jhargram also in Midnapore, West Bengal. There are other examples around Mejhia, Taldangra and Kurkutia in Bankura district. The water-table of the lateritic cliffs of the West Coast often lies below 35 feet from the surface, and seepages are occasionally visible in the valleys at the base of these cliffs.

Copious supplies of water were obtained at Charbatia, near Cuttack, in Orissa, from a bore-hole sunk in 1942 through 52 feet of laterite, 48 feet of grit and sand, into 12 feet of the decomposed upper part of the underlying bed rock. In the Birbhum district of West Bengal, conditions more or less favourable for tube-wells occur in the neighbourhoods of Murarai and Nanur, within a depth of 60 feet, according to B. C. Gupta. A tube-well at Paiker, with a depth of 214 feet, gave 1,200 to 1,400 gallons per hour, but around Nanur good supplies are generally available from 100 to 150 feet below the surface. Around Bolpur and Ilam Bazaar, conditions are more uncertain: the existing tube-wells at Bolpur have an average depth of about 100 feet and give about 250 to 500 gallons per hour in the dry season. As regards the northern part of the Midnapore district, the most successful tube-wells are located to the east of the Eastern Railway: only one example need be quoted, where, at Suniakon, 4 miles from Garhbeta railway station, a tube-well, 265 feet deep, yields 2,000 gallons per hour under artesian conditions.

The 'valley fills' of the Eastern Ghats, which may be taken as typical of those of other hilly regions of the Peninsula, are usually entirely composed of very porous, detrital deposits, often up to 80 or 100 feet in thickness, as at Rayagada, in the Koraput district of Orissa. In such locations it is obvious that borings must be driven through such materials and penetrate well into the upper, decomposed surface of the underlying, basement rocks in their search for ground-water supplies.

In the Purna basin of Berar, the alluvium in the north of the basin along the Satpura Hills yields plenty of potable water within 15 feet from the surface but elsewhere the water, according to A. K. Roy, is saline, unfit for drinking or irrigation. The salinity decreases as one proceeds away from the Purna river.

OTHER EXAMPLES

The valley fills of the montane tracts such as those just described differ entirely from the alluvial deposits of the smaller rivers when they reach lower elevations and possess flatter gradients, and again, from the very deep alluvial ones of the greater rivers of the country. All have their own general characteristic underground, hydrological conditions, modified in many cases by local geological features which it is the task of the water prospector to study and

understand. The Imphal plain of Manipur is formed from a valley fill, caused by the damming of the Manipur river by a vast landslide which resulted in the formation of a lake. As the rivers draining into the valley flow over soft, fine-textured rocks, it is probable that the lacustrine deposits of the plain consist mostly of clays, muds and silts, with subordinate sand beds derived from the denudation of the sandy Barail Series. The water-table in the wet season lies close to the surface but the water itself is unfit for drinking. This also applies to the permanent water available from sand beds which underlie clays about 100 feet below the surface. There are several salt springs in and around the plain and it would appear that wherever water is found it is likely to be slightly saline. In Tripura, on the other hand, the water-table of the valleys is close to the surface and is at times under sub-artesian conditions. For the general conditions obtaining over the great plains of the Brahmaputra, in the Assam valley and northern Bengal, the opinion of H. A. C. P. Hetherington may be quoted: 'Assam and North Bengal,' he writes, 'may probably be classified among the most free yielding areas of underground water supplies in the world. Water is available in large quantities and in most parts at comparatively shallow depths. Water levels are as a rule high, but in no case so far have permanent artesian conditions been encountered.' At the same time, though the ground water nearer the surface is generally pure, as depth increases it tends to become more and more ferruginous, though the geographical distribution of this iron content is very capricious. In Assam, the underground water invariably contains between 0.01 and 0.9 parts of iron per 100,000. Burhanpur, a town lying on the alluvium of the Tapi (Tapti) valley in the Nimar district of Madhya Pradesh, has had the distinction of a novel water service since 1650, when, states A. K. Roy, percolation tunnels were driven underground to arrest the flow of the subsoil water into the Tapi. It is then led through conduits to reservoirs before being distributed through masonry water-towers. Two wells on the bank of the Tapi furnish supplementary supplies. Dr A. L. Coulson has described an unusual case from the Mardan and Peshawar districts of the North-West Frontier Province, Pakistan, where a barrier of impervious slates crossing the gorge of the Indus at Attock has restricted the drainage of the Kabul valley and caused equalization of the ground water and possibly rendered it harder. In some parts of the alluvium-covered plateau of Rawalpindi, deep pockets of gravel give rise to conditions favourable for the accumulation of artesian and sub-artesian supplies and a number of wells are in operation around the town. The great Margala submontane slope forms an efficient reservoir for underground water.

The surface water supply of Rangoon is augmented from tubewells, of which 17 were in operation in 1893, but by 1930 over 400 had been drilled, of which about half were working and yielding

GROUND-WATER PROVINCES

(after J.

PROVINCE	SUBPROVINCE	PRINCIPAL MANNER OF OCCURRENCE OF GROUND WATER
Northern Montane Zone	Mountains	Run-off high, except under snow. Percolation in joints, bedding planes, scree gullies and surface-creep materials.
	Valley-fill Deposits	Pore spaces of gravels and sands.
	Ganga Basin	Abundant quicksands. Water-table high. Ground water mostly fresh. Some areas of sodium carbonate and sodium sulphate efflorescence.
Indo-Gangetic Alluvium	Punjab Alluvial Basin	Water-logging towards the south-west and probably quicksands. Water-table low towards the north-east. Soils generally more alkaline than those of the Ganga Basin.
	Indus and Jacobabad Basins	Water-table low and in some parts more than 300 feet below surface level. Saline water general.
	Archaean	Water in joints, fissures, crush zones and foliation planes in the weathered zone.
Peninsula	Cuddapahs and Vindhyan	Most of the rocks possess low porosity. Water is in joints and bedding planes.
	Gondwanas	The shales are of low porosity while the sandstones are usually of higher porosity.
	Deccan Traps	Usually of low porosity but water is found in the laterite cappings of wide plateaus and in the surface, bouldery, weathered rock.
	Mesozoic and Tertiary Sedimentaries	The rocks with the higher porosities hold part of their water internally, as well as in their bedding and joint planes.
	Western Rajasthan	Except along the Luni basin, the depth of the water-table exceeds 100 feet and in places is as low as 400 feet. Ground water occurs at a higher level below the few rivers than away from them. Salinity is high and in places above permissible limits.
	Coastal and River Alluvium	As in the Indo-Gangetic alluvium.

¹ Wells fed by percolation from the surrounding materials.² Long

OF INDIA AND PAKISTAN

B. Auden)

METHODS OF RECOVERY
OF GROUND WATER

Springs.

Tube-wells, percolation wells,¹ *karezes*.²

Tube-wells, percolation wells, *mota* wells.²

Tube-wells, percolation wells.

Deep percolation wells. In regions where the water-table is raised by infiltration from rivers, tube-wells. Infiltration galleries.

Percolation wells with infiltration galleries. Some drilled wells.

Percolation wells with infiltration galleries. Some drilled wells. Springs.

Percolation wells.

Percolation wells. Springs.

Percolation wells. Tube-wells in rocks with sufficient porosities and transmitting properties which are not saline. Springs.

Present information indicates that ground water is not abundant and may be scarce except seasonally along the Luni river.

Tube-wells, etc.

underground channels. ² Hand-dug wells with a tube-well below.

DETAILS OF SOME SOUTH INDIAN ARTESIAN WELLS

DISTRICT AND TALUK	LOCALITY	DEPTH OF BOREHOLE IN FEET	SIZE OF BOREHOLE IN INCHES	HEIGHT OF DISCHARGE FROM GROUND LEVEL IN FEET	MAXIMUM YIELD IN GALLONS PER MINUTE	GEOLOGICAL FORMATION
West Godavari Tadapalligudem	Vungutur ..	185-265		22½	210	Alluvium probably underlain by Tertiary sandstone. Close to Rajahmundry sandstone outcrop.
ditto	Chebrole ..	326		1	4	ditto
ditto	Anantapalle ..	215		4	10	Gondwana sandstone. Below alluvium.
East Godavari Kakinada	Peddabrahmadevam	148-254		19	120	Alluvium probably underlain by Tertiary sandstone. Close to Rajahmundry sandstone.
East Godavari Peddapuram	Rangapuram ..	130		2	35	Alluvium probably underlain by Tertiary sandstone. Close to Rajahmundry sandstone.
South Arcot Vridhachalam	Azinagar ..	125-155	4-6	3	13	Tertiary sandstone.
ditto	Kavanpur ..	196-268	4-7	3	350	ditto
ditto	Keelpalur ..	250	6	4	400	ditto
ditto	Devangudi ..	235	6	3	225	ditto
ditto	Kumaramangalam ..	123-220	6	4	420	ditto
ditto	Peruvurappur ..	328-363	4	3	450	ditto
ditto	Valayamadevi ..	410	5	3	1,000	ditto
Tiruchirappalli Udayarpalaiyam	Srinivasapuram ..	130	4	2	30	
Pondicherry	Savana ..	174		9	30	Alluvium underlain by Tertiary sandstone.
ditto	Upalem ..	119		9	100	ditto
ditto	Botanical Garden ..	261		9	145	ditto

perhaps 4 million gallons per day. They draw their supplies from four gravel beds, about 10 to 20 feet thick, in the Lower Delta Alluvium and lying at depths of 120, 150, 250 and 350 feet approximately below the surface of the Upper Delta Alluvium near the Rangoon river, and at somewhat lesser depths further inland. The catchment area is on the Irrawaddian rocks of the long, narrow spur of the Pegu Yomas, on and around the lower slopes of which the city lies. These rocks consist of sands, sand rock, soft sandstones, shales and clays with a few bands of harder, calcareous sandstone. Artesian conditions are rarely met with but sub-artesian conditions prevail, the water often rising to within a few feet of the surface. On the lower ground, however, there is no true static level as the water level rises and falls several feet with the flow and ebb of the tides in the Rangoon river. There is thus a delicate hydrostatic balance, and the fate of the underground water supply of Rangoon depends on the ingress of salt water. In certain areas, where over-drilling has taken place, the wells have already become brackish and in 1930, acting on the advice of its Geological Party, the Government of Burma passed the Burma Underground Water Act, under which the sinking of tube-wells was regulated and controlled. For further details a comprehensive report by P. Leicester entitled 'The Geology and Underground Water of Rangoon' should be consulted.

Essential though underground water supplies may be to the economy of communities fortunate enough to live in areas where they are obtainable, irrigation from rivers or from artificial reservoirs is more important, and in some cases is the only means of saving wide regions from those misfortunes which visit them from time to time through failure of the rains. Vast though many of the earlier irrigation works are, and in the Punjab alone there are said to be 16,000 miles of canals, while the Lloyd Barrage Canal System of Sind, completed in 1932, is one of the largest of its kind in existence, much still remains to be done, for India utilizes only 6 per cent of the flow of her rivers today. As many of the existing works, and others under construction or projected, are built not only for flood control and large-scale irrigation, but also for the generation of hydro-electric power, and as the provision of such power is essential for the development of the electro-metallurgical and electro-chemical industries, a brief reference to them may not be out of place in a book concerned with the distribution and provision of the raw materials on which these industries depend.

Until 1945 water development schemes were the concern of the individual provinces, but at a later date the Central Waterways, Irrigation and Navigation Commission and the Central Technical Power Board were constituted to collect and collate data for the systematic employment of all the water resources of the country. Many schemes have been investigated by these two bodies, which

now exist under the titles of the Central Water and Power Commission and the Damodar Valley Corporation.

Under the Development Programme for 1951-6, no less than 10 major and 187 minor irrigation projects to bring more land into cultivation are planned, as well as 10 schemes for the large-scale drilling of tube-wells at various places. In addition to this, work has already commenced on seven great multipurpose undertakings which include the Damodar Valley Project, the Hirakud Project and the Bhakra and Nangal dams across the Sutlej river, their respective estimated costs being Rs 750, 700 and 1330 millions, or a total of £208.5 millions. The Damodar river will be harnessed, and its destructive floods ended. Out of the eight storage dams ultimately proposed for this project, four are under construction, with hydro-electric stations to possess an installed capacity of 124,000 kilowatts, while an irrigation barrage with its associated canals and distributaries will provide water for about one million acres. The Hirakud Project envisages the construction of a dam across the Mahanadi to supply water to the surrounding country and also for two power houses of 123,000 kilowatts capacity initially. The three projects already mentioned, those of Damodar, Hirakud and Bhakra-Nangal, are expected to bring 2 million acres of new land under cultivation by 1955-6 and to increase electricity generating capacity by 338,000 kilowatts. Other large multipurpose schemes include the Tapi Project in Bombay, the Tungabhadra Dam, one end of which has been built from Hyderabad and the other from Mysore, the Chambal Project in Madhya Bharat and the Kosi Barrage in Nepal.

On p. 680 a list is given of the important water-power projects at present under construction or examination in India, and to it are added data as well as an older preliminary forecast of some of the water-power resources available in Burma. In the preparation of this list we have had the benefit of the assistance of Sirdar Balwant Singh Nag of the Central Water and Power Commission, to whom we wish to express our thanks. The locations of the existing and projected works are shown on Map XI and it is demarcated into the six great natural divisions or catchment areas enumerated in the table on p. 679 which tabulates the available water and hydro-electric power of the principal Indian rivers. The particulars of the catchment areas shown in the map and the data given in the table are from R. D. Dhir's 'Utilisation of Water Resources in India' (*Indian Journal of Power & River Valley Development*, Vol. 2, No. 6, 1952).

The effects that the many undertakings, large and small, now in process of construction, are likely to have in the near future both in bringing new land under irrigation and so increasing the quantities of food and cash crops, and of raising India's electrical generating capacity and so assisting her industrial expansion, were summarized in November 1952 by Mr M. S. Thirumale Iyengar,

Chief Engineer of the Tungabhadra Project, speaking at the 25th annual session of the Central Board of Irrigation and Power, in New Delhi, as follows:

'The cumulative storage capacity of reservoirs completed prior to 1947 was eight million acre feet. Since 1947, there have been about 19 dams under construction, large and small, among which the Bhakra-Nangal, the Damodar Valley, the Hirakud and the Tungabhadra would store about 18 million acre-feet and the rest of the dams 20 million acre feet. Included in the Five-Year Plan are some large dams that will give a total of 35.4 million acre-feet capacity. When these are completed we will have in all storage reservoirs with an aggregate capacity of about 90 million acre-feet. The power that will eventually be developed in all these sites would be (1) 0.5 million kilowatts from works done prior to 1947, (2) 1.93 million kilowatts from dams now under construction and (3) 3.1 million kilowatts from the projects contemplated in the Five-Year Plan. All these together would give an aggregate total of 5.5 million kilowatts. Also the irrigated area will increase from 40 million to 70 million acres. All this vast irrigated area would be entirely dependent upon the waters stored and diverted or directly diverted from river diversion works.' For the benefit of the non-technical reader, it may be explained that one acre-foot represents the amount of water required to flood one acre to a depth of one foot and that the increase of 30 million acres in the irrigated area is the equivalent of 46,875 square miles; for the sake of comparison England has an area of 50,874 square miles.

According to the Report of the Commonwealth Consultative Committee known as 'The Colombo Plan', the hydro-electric potential in Pakistan is between 5 and 6 million kilowatts, against which the installed capacity in 1950 was but 9,600 kilowatts. It was then proposed to build new stations capable of generating an additional 200,000 kilowatts of hydro-electric power, which, with about 56,000 kilowatts of new thermal power, were to cost Rs 450 million or nearly £50 million. These supplies of energy were to be devoted to the operation of extensive tube-well and irrigation projects, to the development of various industries and to the modernizing of the coal mines. Amongst the 12 new stations contemplated are the multipurpose projects of Warsak (installed capacity of 90,000 kilowatts) and Karnafulli (in Eastern Pakistan, with an installed capacity of 40,000 kilowatts) and the hydro-electric projects of Mianwali (installed capacity 30,000 kilowatts) and Dargai (installed capacity 20,000 kilowatts). In addition to these, the Rasul Tube-well Project provides for the drilling of 1,800 tube-wells, to be operated by electricity from the Rasul hydro-electric station, to irrigate some 712,000 acres and to assist in lowering the water table of a considerable portion of the area now lying waterlogged in the Punjab. Other anti-waterlogging measures by means of tube-wells have also been proposed to deal

with the affected areas, which now total about 2·3 million acres and are being increased at the rate of 40,000 acres annually. About 100 miles from the mouth of the Indus, the Lower Sind barrage is under construction to irrigate an area of 2·8 million acres. The Taunsa barrage, to be completed in 1956-7, across the Indus, 180 miles downstream from the existing Tinnah barrage at Kalabagh, will irrigate 1·4 million acres in Dera Ghazi Khan and Muzaffargarh districts. The Guddu Barrage Scheme envisages a dam on the Indus about 80 miles upstream from the Sukkur barrage, to irrigate over a million acres of land in Upper Sind, bordering on Bahawalpur State. The Ganges-Kobadak Project will provide improved water supplies to 2·2 million acres in East Bengal and electric power during the flood season.

The Second Annual Report of the Colombo Plan, published in December 1953, stated that the capacity of the Mianwali hydro-electric station had been raised to 100,000 Kw., that the Dargai station would be commissioned in 1954, that work was proceeding on the Warsak Project and that the capacity of the Karnafuli Project, in East Pakistan, on which work is in progress, to serve an area of 15,000 square miles, will be 160,000 Kw. It refers also to the hydro-electric projects in connexion with the Punjab Canal Links, to the Kurram Garhi Project for the generation of 4,000 Kw., and to the Chuharkana Reclamation Project, which through tube-well irrigation will bring 120,000 acres under crops by 1956-7.

It has later been announced that the Government of Canada has allocated financial aid for the Warsak Multipurpose Project, and that the capacity of the thermal power stations, both steam and diesel driven, in Pakistan generally, is to be increased to a total of 130,000 Kw. by June 1956.

The preliminary data are also available for a large number of similar schemes in Burma which will also receive attention in due course. In the Journal of the Bureau of Flood Control and Water Resources Development of the United Nations Economic Committee for Asia and the Far East, for January 1953, details are given on the Multipurpose Yamethin District Project which will harness the upper waters of the Sittang river, provide irrigation for 510,000 acres, power of 50,000 Kw. and flood control of the river basin above Toungoo, together with those of the Yezin Dam Project to irrigate 51,000 acres. In the same Journal for June, 1954, it is stated that the Saingdin Falls power station, near Buthidaung, in Akyab, should be completed before 1957, to provide 60,000 Kw. to three districts in Arakan and to the paper mills at Ponnagyun, a caustic soda plant in Akyab and the salt works at Kyaukpyu. It was further stated in February, 1954, that priority had been given to the construction of this power station, to the hydro-electric plants on the Pegu river and to those of the Balu Chaung, near Loikaw, in the Southern Shan States.

AVAILABLE WATER AND HYDRO-ELECTRIC POWER OF INDIAN RIVERS

Regions	Water available (in million acre-feet) per year	Hydro-electric power (in million Kw.)	
		Installed Capacity	Hydro-electric Potential
1. Catchment of areas of rivers flowing into the Arabian Sea. The Indus excepted.	256.36	0.250	3.5
2. Catchment area of rivers flowing into the Bay of Bengal. The Ganga and Brahmaputra excepted	341.13	0.172	12.5
3. Catchment area of the Brahmaputra in India	309.78	0.0005	11.0
4. Catchment area of the Ganga system in India	376.35	0.050	10.5
5. Catchment area of the Indus system in India	62.35	0.025	2.5
6. The Dry Zone in western Rajasthan .. ..	....	0.005	....
	1345.97	0.50	40.00 approx.

NOTE:—The acre-foot is the quantity of water required to cover one acre to a depth of one foot.

IMPORTANT HYDRO-ELECTRIC PROJECTS IN INDIA

Existing hydro-electric projects and dams are shown alphabetically while those under construction or examination are indicated numerically.

Map Index (1)	State or Region (2)	Name of scheme (3)	Nature of scheme (4)	River involved (5)	Installed Power in K.w. (6)	Area proposed for irrigation in acres (7)
A	Kashmir	Mohora ..	Hydro-electric	Jhelum	3,200	....
B	"	Jammu ..	"	....	1,040	....
C	Himachal Pradesh	Sindh Valley project, Gandarbal ..	"	Sindh	6,000 initially	....
2		Jogindarnagar	"	....	48,000	....
3		Bhakra dam & Nangal project	Hydro-electric, irrigation	Sutlej	Bhakra : 900,000 initially Nangal : P.H. 1 : 48,000 ¹ +24,000 P.H. 2 : 48,000 +24,000	10,000,000 (6 million E. Punjab) (3 million PEPSU) (1 million Rajasthan)
4	East Punjab			....	1,750	....
D	Himachal Pradesh	Bilaspur (Chaba ?) ..	Hydro-electric	Jamuna	17,000 + 34,000	....
5	Uttar Pradesh	Jamuna project ²	"	....	3,000	....
E	"	Musoorie ..	"	Ganga canal	20,400	....
6	"	Pathri ..	"	"	4,400	....
F	"	Bahadrapur ³ ..	"	"	9,300	....
G	"	Mohammadpur ..	"	"	5,000	....
H	"	Nirajini ..	"	"	3,000	....
I	"	Chitaura ..	"	"	3,000	....
J	"	Salawa ..	"	"	3,000	....

¹ Completed.

² Temporarily postponed.

³ To be abandoned after the Pathri hydro-electric power comes into commission.

K	Utter Pradesh	Bhola	Hydro-electric	Ganga canal		
L	"	Palra	"	"	2,700	....
M	"	Sumra	"	"	500	....
7	"	Nayar	"	"	1,200	....
8	"	Ramganga	Multi-purpose	Nayar	....	....
9	"	Khatima	"	Ramganga	....	....
10	"	Rihand dam power project	Hydro-electric	Sarda canal	41,400	....
	"		Multi-purpose	Rihand	....	2,384,000
11	"	Dukhwan	Hydro-electric	....	240,000	....
	Bihar	Damodar	Multi-purpose	Damodar	....	1,000,000 total
12	"	Konar dam... Valley Corpn. (D.V.C.),	"	Konar	40,000	....
13	"	Tilaiya dam project	"	Barakar	4,000 initially	....
14	"	Konar (1 & 2) ¹	"	....	6,000 ultimate	....
15	"	Aiyar dam project	"	Tributarics of Damodar	16,750	....
16	"	Berno project	....	Bokaro	45,000	....
17	"	Bokaro dam	Multi-purpose	....	Abandoned	....
18	"	Baldahari project	"	Barakar	32,000	....
19	"	Maithon dam project	"	"	20,000	....
20	"	Panchet hill project	"	Damodar	40,000	....
21	Bihar & Nepal	Kosi project	Hydro-electric, irrigation, flood control	Kosi	40,000	....
					20,000	1,397,000
22	West Bengal	Mayurakshi (Mor)	Hydro-electric, irrigation	Mayurakshi	4,000	120,000
N	"	Darjeeling	Hydro-electric	....	1,960	....
23	Orissa	Mahanadi (Hirakud)	Multi-purpose, including flood control	Mahanadi	123,000 I stage	1,928,000
					160,000 ultimate	
24	"	Tikarpura	....	"	....	....
25	"	Naraj	....	"	....	....

¹ Amalgamated with Konar dam.

IMPORTANT HYDRO-ELECTRIC PROJECTS IN INDIA—Contd.

Existing hydro-electric projects and dams are shown alphabetically while those under construction or examination are indicated numerically.

Map Index (1)	State or Region (2)	Name of scheme (3)	Nature of scheme (4)	River involved (5)	Installed Power in Kw. (6)	Area proposed for irrigation in acres (7)
26	Madhya Bharat-Rajasthan	Chambal hydro-electric scheme (Chowraigarh)	Hydro-electric, irrigation	Chambal	69,000 I stage	700,000 in Madhya Bharat 700,000 in Rajasthan 529,000
27	"	Rawatbhata	....	"	64,000	
28	"	Kotah	....	"	42,000	
29	Madhya Pradesh	Bargi	....	Narmada	....
30	"	Wainganga	....	Wainganga	....	.... .... 529,000
31	Bombay	Tapi river hydro-electric cum irrigation project, Kakarpara	Hydro-electric, irrigation	Tapi	24,000 initial	
32	"	Koyna hydro-electric project	Hydro-electric	Koyna	240,000 I stage	....
33	"	Radhanagari hydro-electric project	Multi-purpose	Bhogavati	4,800	32,000
34	"	Kalinadi hydro-electric project	Hydro-electric	....	60,000	....
O	"	Bhivpuri	"	....	72,000	....
P	"	Khopoli	"	....	70,000	....
Q	"	Bhira	"	....	110,000	....
R	"	Bhatgar	"	....	1,024	....
S	Mysore	Jog (Mahatma Gandhi scheme)	"	Sharavati	120,000	....
T	"	Shimnapura	"	Cauvery	17,200	....
U	"	Cauvery power scheme	"	"	42,000	....

35	"	Lakkavalli ..	..	Hydro-electric, irrigation	Bhadra	..	17,000	180,000
36	"	Mahatma Gandhi Extn. 2.	Gandhi	Hydro-electric	Sharavati	..	Included under S-Jog, as Extn. 2	....
37	Hyderabad	Nizamsagar project ..	..	Hydro-electric, irrigation	Manjira	..	15,000	275,000
38	Hyderabad- Mysore	Tungabhadra	..	Hydro-electric, irrigation	Tungabhadra	..	18,000 Hyderabad 36,000 initially Andhra	750,000 Hyd. 457,000 Andhra 172,000 Mysore
39	Andhra	Ramapadasagar	..	Hydro-electric, irrigation	Godavari	..	150,000 firm ¹	2,750,000
40	Andhra- Orissa	Machkund hydro- electric scheme	..	Hydro-electric	Machkund	..	102,000	....
41 } 42 } 43 }	Andhra Madras " "	Krishna-Penner Pro- ject Pykara .. Mettur .. Papanasam .. Moyar .. Mekadatu ..	Pro-	Hydro-electric, irrigation Hydro-electric " " " " " " " "	Krishna Penner Pykara Cauvery Tambiraparni Pykara tailrace ²	43,000 (71,000 ultimate) 40,000 28,000 36,000 22,000 tentative	3,000,000	
45	Madras- Mysore	Kundah	..	" "	Kundah	..	250,000	....
46	"	Periyar	..	" "	Periyar	..	75,000	....
47	Assam	Umtru	..	" "	Umtru	..	4,000	....
48	Travancore- Cochin	Pallivasal hydro- electric scheme	..	" "	Muthirapuzha	..	37,500	....
49	"	Sengulam hydro- electric scheme	..	" "	" tailrace ³	..	48,000	....
50	"	Poringalkuthu hydro- electric scheme	..	Hydro-electric, irrigation	Chalakudy	..	will use Pallivasal tailrace. 24,000 1 stage	10,000
	"	Madhupathy dam (to support Palli- vasal Power Stn.)	..	....	Muthirapuzha	..	....	....

¹ Continuous power as opposed to seasonal power.² Discharged water.

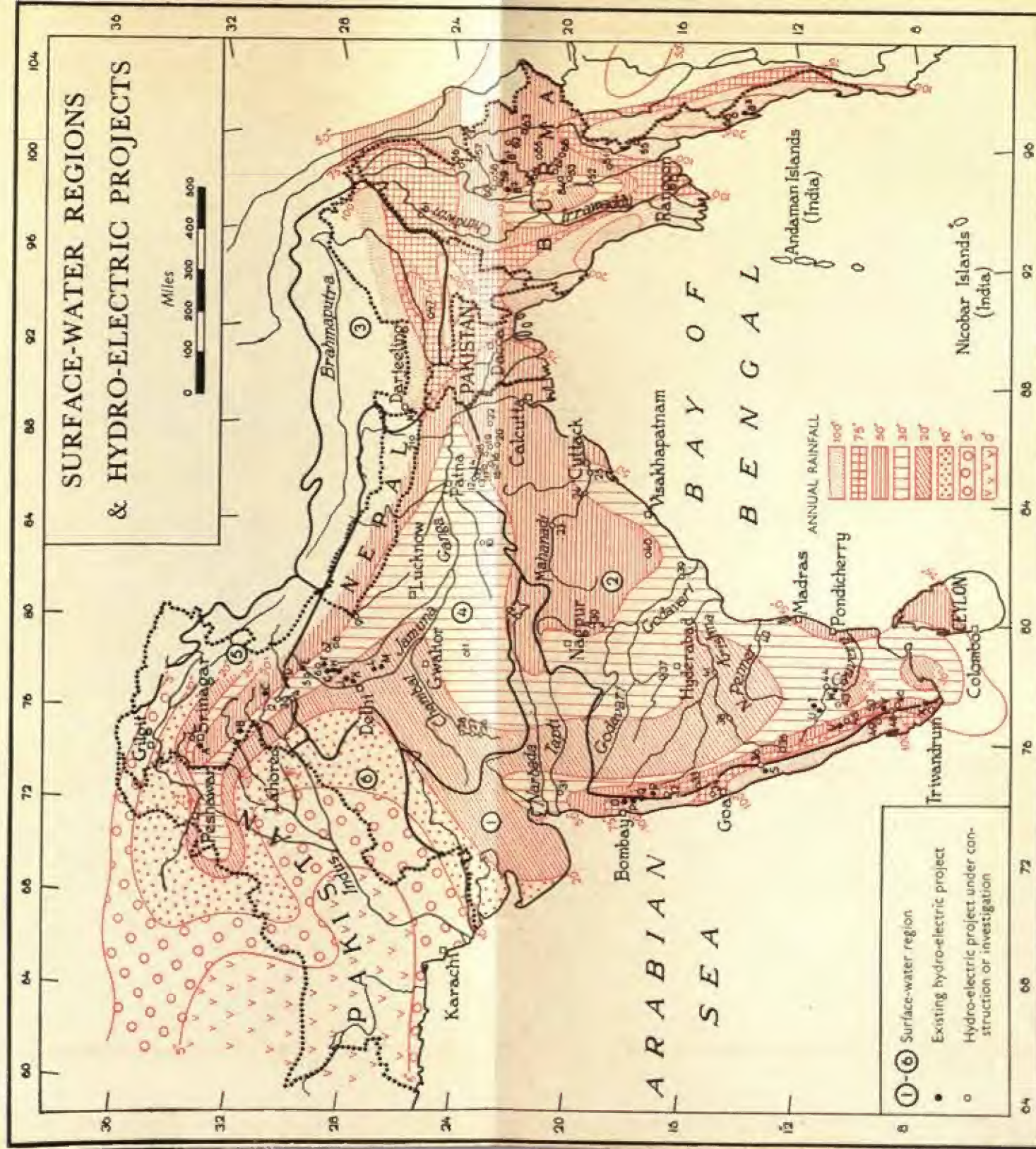
HYDRO-ELECTRIC PROJECTS AND SOME PRELIMINARY FORECAST OF THE WATER-POWER RESOURCES IN BURMA¹

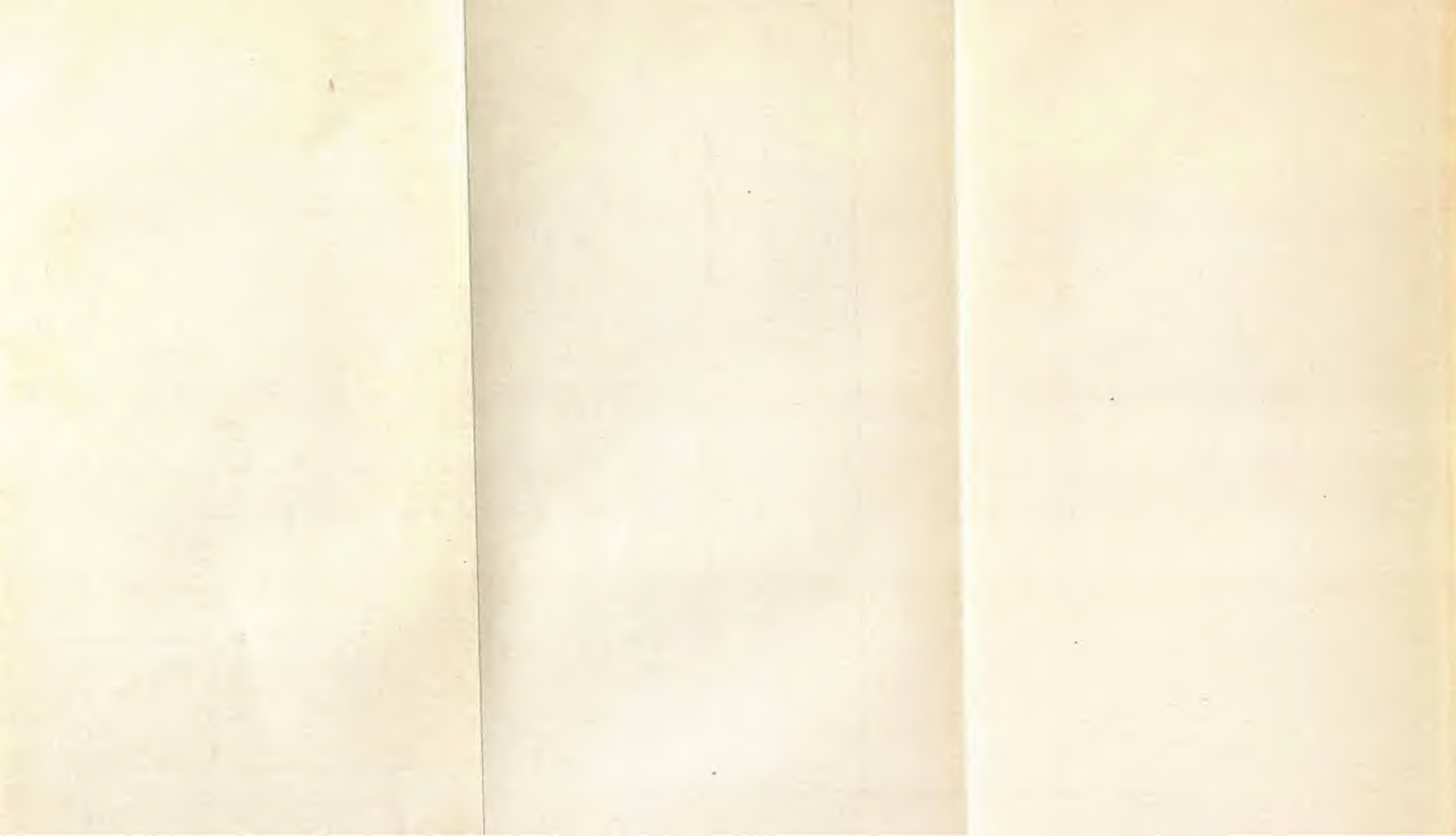
The existing hydro-electric projects are shown as B₁, B₂, B₃

Map Index (1)	District or region (2)	Site (3)	River or stream involved (4)	Nature of supply (5)	Continuous power in K.w. (6)
51	....	....	Thaukyegat	Flow & storage	4,000
52	....	....	Sittang	"	4,000
53	S. Shan States ..	....	Balu ..	Flow	3,300
54	" ..	....	Hcho ..	"	2,950
55	....	....	Salween ..	"	120,000
56	Upper Burma ..	....	Taping ..	"	17,000
57	" ..	....	Shweli ..	"	250,000
58	Mogok ..	....	Konwet (Kinwe)	"	2,000
59	" ..	....	Bernard Myo	"	2,000
60	N. Shan States ..	....	Chuanggyi	"	1,400
61	Upper Burma ..	....	Chindwin	"	6,000
62	N. Shan States ..	....	Namma ..	"	2,400
63	S. Shan States ..	....	Nam Pang	"	11,000
64	Maymyo ..	....	Anisakan	Flow & storage	150
65	S. Shan States ..	....	Zawgyi ..	Flow	8,000
66	" ..	....	Nam Teng	"	13,000
67	" ..	....	Panlung	"	24,000
B ₁	N. Shan States ..	....	Mansan falls	"	2,400
B ₂	Mogok ..	....	Yaynee & Yaybu	....	410
B ₃	Tavoy ..	....	Sin yat ..	....	375
68	Tenasserim ..	....	Talainga	Flow	450

¹ J. W. Mearns, *Triennial Report with a preliminary forecast of the water-power resources of India*, Hydro-electric Survey of India, Vol. III, 1921.

MAP XI





CHAPTER XIX

SOILS

THE soils which cover much of the solid surface of the earth, support its natural vegetation and supply the food for the crops planted by mankind, are for most countries their most valuable possession. They fall into two great natural classes—the sedentary soils remaining more or less in the places where they were formed, and the transported or alluvial soils; but there is no hard and fast line between them, for the alluvial soils on the margins of valleys grade insensibly into the sedentary soils of the uplands. Soils are the products of rock decay in which both mechanical disintegration and chemical decomposition play their parts, but the nature of the parent rock is not the sole determinant of the character of a soil: different rocks sometimes give rise to similar soils and the same rock may develop soils of varying composition. Nevertheless, as far as India, Pakistan and Burma are concerned, as Dr D. N. Wadia has observed, 'the principal characters of the main soil groups are generally deducible from the nature of their geological foundation'.

The soil-forming processes, at work through the whole profile from surface to bed rock, vary with rainfall and temperature, altitude and topography, the character of the surface vegetation, the activities of living organisms and the effects of dead ones in the soil itself, the work of the cultivator and the length of time that all these and other agencies have been in operation. The alternating wet and dry seasons of the monsoon have a profound effect in the development of our soils, the lateritic soils of India and Burma, for instance, being unknown in more temperate climates. Again, the soils of the Peninsula, one of the oldest land surfaces of the earth, are of very great antiquity in contrast with the drift soils of Europe, Russia and North America which are largely of post-Glacial and sub-Recent growth. The latter are more nearly related to the young and immature soils of the Indo-Gangetic plain dating from Middle Pleistocene times.

Chemical analyses of soils reveal their composition, assess their available stores of plant foods and determine how they can be improved by fertilizers, but too much reliance should not be placed upon them as reliable guides to the agricultural responses of any particular soil. Mechanical analyses determine the physical constitution of soils and indicate the size of the clay content. 'Clay', states Sir William Ogg, 'is the most chemically reactive portion of the soil and is of great importance not only in crop

nutrition but also in connexion with such physical properties as plasticity and cohesiveness.' He adds that soil clays, formerly regarded as amorphous gels consisting mainly of kaolinite, are now known to be complex substances containing a wide range of crystalline minerals the large surfaces of which play an important part in the transfer of nutrients from soils to plants, in the absorption of moisture and in soil structure.

Three fundamental soil divisions are recognized in our region :

(a) The mature soils of the Peninsula south of the Vindhya mountains, in which, in Dr Wadia's words, 'the effect of ages of rock-forming processes has been to obliterate more or less the influence of parent rocks'. They include the great zonal groups of Indian soils, the red, black, laterite and lateritic kinds which exhibit wide variations in their clay factors, structure, texture, porosity, content of organic matter and presence or absence of calcareous and ferruginous segregations. Besides these major types there are many others of more limited distribution, such as the yellow sandy soils and the stony and sandy soils of the Gondwana basins.

(b) The alluvial soils of India and Pakistan covering the great plains from Sind in the west, northern Rajasthan, most of Uttar Pradesh, most of Bihar and Bengal and half of Assam in the east. Over vast areas these soils are more or less uniform in colour, constitution, porosity and organic components, but there are many minor variations giving rise to subordinate groups amongst them. The division also includes dry and wet meadow, semi-desert and deltaic types as well as saline and alkaline soils.

(c) The scanty soils of the mountains of Pakistan, the Himalayas and the ranges of far eastern India, regions in which sandstones, clays and limestones, mainly of Tertiary age, form the fundamental groundwork. These are the least mature of all the soils, liable to constant erosion and removal. Of restricted extent except in the intermontane basins, they include mountain-meadow, grassland and forest type soils, alluvial rice land and podsolized soils as well as varieties typical of bogs and marshes, talus accumulations, scree and residual materials left by the weathering away of limestones and dolomites.

PRINCIPAL SOIL GROUPS OF PENINSULAR INDIA

Laterite and Lateritic Soils. This group occupies a belt of varying width round the Peninsula and occurs also on the plateaus of Malwa, central India, Madhya Pradesh, Vindhya Pradesh, Bihar, Orissa, parts of the Eastern and Western Ghats, Hyderabad, Assam and East Bengal. Its distribution in Burma is referred to later. Laterites result from the weathering of any rock, except perhaps pure quartzites and similar siliceous material, under tropical or sub-tropical conditions of alternating humidity and aridity, by

which the alkalis and silica contents are leached away and the residual components enriched in the sesquioxides of aluminium and iron in varying proportions. Lateritic soils, like the red soils and the black soils to be described below, have developed a more or less distinct profile and thus constitute a zonal group of their own.

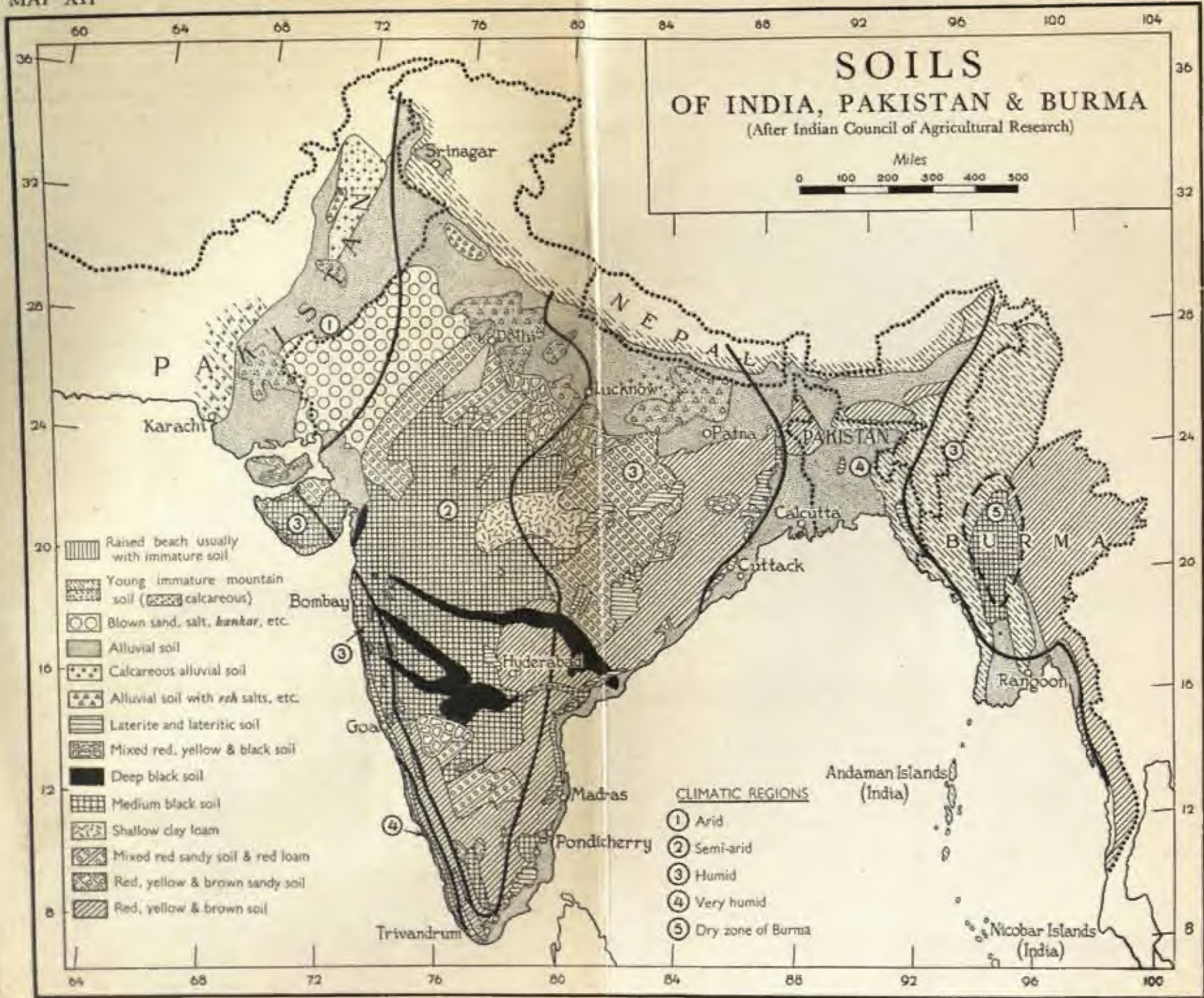
Laterite itself forms thin, gravelly, reddish loams, usually with a profile of only a few inches, though they may lie on the surface of laterite caps often scores of feet thick. The processes inherent in their formation account for their composition being mainly of oxides of iron and aluminium and free quartz grains: they lack alkalis and are notably deficient in phosphoric acid, lime and magnesia. They have been denuded of humus and exchangeable bases and are left with a more or less acid reaction. They are not retentive of moisture and are of little value for crop production generally; at the same time, centuries of prolonged tillage and the secondary changes it has brought about have resulted in soils of fair quality from such unpromising material in parts of the Bombay Deccan.

The foregoing remarks apply only to the high-level laterites and their soils, but there is also a group of low-level laterites, the best examples of which amongst many are to be found at short intervals all the way from near Cape Comorin to the Orissa coast and thence northward through Midnapore, Burdwan and Birbhum to the flanks of the Rajmahal Hills, where they are well developed and appear to pass into the high-level laterites. They are not such massive formations as their higher relatives, are frequently conglomeratic and include fragments of gneiss and other rocks. Some of them are due to the reconsolidation of fragments derived from high levels, and the soils during their downward creep become intermingled with materials from other sources, eventually giving rise to the heavy loams and clays of the lowlands in which they are found. By reason of their heterogeneous origin such lateritic soils respond better to agriculture than those derived solely from the high-level laterites. Though the ultimate processes involved in the formation of laterite and lateritic soils are still not thoroughly understood, the group is a well-defined one and the terms should not be employed, as is frequently the case, to designate other red earths and soils which originate by different means and possess few if any of their peculiar chemical and physical properties.

Red Soils. This, the largest soil group of India, includes many varying types clothing the rocks of the Archaean System of the Peninsula from Bundelkhand in the north through parts of Madhya Pradesh, eastern Hyderabad, south-eastern Bombay, Mysore, Andhra and Madras, to the extreme south, as well as parts of south Bengal and Orissa, a total area of the order of 800,000 square miles. The parent rocks are mainly acid granites and gneisses, though the ancient sedimentary sandstones, slates and shales of the Cuddapah

and Vindhyan Systems have also added their contributions, the soils from the shales naturally being finer textured than the sandy varieties from the other rocks. Their general red colour is due to their iron content, derived originally from ferro-magnesian silicates, but the colour changes greatly from place to place and may assume brown, yellow, grey or even black shades, owing not only to variations in iron content but also to imperfect hydration as a result of poor drainage. The soils of the uplands are usually red, thin and gritty; those of the plains and valleys darker and more fertile. In the hilly and rocky tracts of the south, true black soils hardly ever occur, the outcrops being almost always covered or surrounded by red soils, but ages of slow soil creep have resulted in much intermingling or in gradation from one type to the other. Compared with the black soils, the red soils as a group are deficient in humus, lime, magnesia, alkalis (though their potash contents are sometimes fairly high), nitrogen and phosphorus. Their soluble base-exchange constituents and their total base-exchange capacity are low. In their general composition they are siliceous and aluminous with much free quartz in the form of sand. As a rule their clay fraction is inadequate to offer good resistance to the forces of denudation, and their productivity varies a great deal with the local rainfall.

Black Soils. The black soils are often referred to as *regur*, a word derived from their Telugu name *regada*, or as 'cotton soils'. They spread across large areas in Bombay, Malwa, Berar, western Madhya Pradesh, Hyderabad, Gujerat and Saurashtra, with extensions into central India and parts of Bundelkhand. Their most characteristic types are found on the plains of the Deccan Trap, in soil mantles of no great depth of profile. In such instances there can be no question but that such soils are residual products of the surface decomposition of the underlying basalts. Throughout the 200,000 square miles which the volcanic rocks of the Deccan occupy, the passage from decomposed basalt into black soil may be seen in thousands of sections. Again, over enormous areas the boundary of the Trap marks the approximate limits of the black soils, and while nothing resembling them occurs in the regions occupied by metamorphic rocks in Bengal, Bihar, Orissa, Chota Nagpur or Chhattisgarh, the black soils appear again in the basaltic Rajmahal Hills. But all the black soils of the country are not associated with basic eruptive rocks, and their distribution is not everywhere coterminous with the Deccan Trap. Apart from transported examples they are associated to a minor extent with granitic and ancient sedimentary rocks in parts of the Cuddapah, Kurnool, Bellary, Anantapur, Coimbatore, Ramnathapuram, Tirunelveli, Salem, Tiruchirapalli and Tanjore districts of Andhra and Madras. Under suitable conditions of climate, temperature and drainage they have originated from



alluvium in river valleys, in freshwater marshes, estuarine flats and salt-water lagoons. Bruce Foote believed that *regur* may be formed 'by organic alteration of the primary products of weathering of almost any rocks, if they are sufficiently argillaceous in quality'. As pedological investigations in India increase the time will come when the great group of black soils will be sorted out and classified each into its proper genetic type.

Even in the Deccan the influence of atmospheric agencies is clearly visible. In the region of the Western Ghats, red, reddish brown or yellowish brown soils are to be found on the higher ground while the black soil is confined to hollows and valley bottoms. The red tints of course betoken the commencement of lateritoid weathering in this mountain region of higher altitude and heavier rainfall. On the other hand in the parched eastern part of the Deccan, pale olive green, somewhat sandy soils occur, the origin of which has still to be explained.

The profile of a typical black cotton soil *in situ* is seldom more than a veneer from 2 to 6 inches thick; transported black soils may be 40 or more inches in depth without any clear differentiation into separate layers. In the main they are clayey loams, dark grey, dark brown, brownish grey, bluish black to black in colour. The clay factor is 62 per cent or more, itself averaging 60 per cent silica, 25 per cent of alumina and 15 per cent of iron oxide. They contain no coarse sand or gravel and almost always carry a layer of calcium carbonate (*kankar*) between the soil and the disintegrated bed rock (*moorum*). They are characterized by high percentages of calcium and magnesium carbonates (6 to 8 per cent), iron oxide 9 to 10 per cent and fairly constant alumina, about 10 per cent. The potash content is variable and generally less than 0.5 per cent while phosphorus, nitrogen and humus are as a rule low. The base-exchange capacity of *regur* is fairly high throughout its profile and it is rather well endowed with replaceable bases. Chemical composition, however, is not a trustworthy guide to the various secondary modifications of the black soil group as a whole, or to the agricultural potentialities of any particular member of it, and further studies of the morphology and physical properties of the profiles are advocated by recent specialists who have examined them.

Regur then in its most prevalent form is highly argillaceous and when thoroughly wetted becomes a tenacious mud, almost impassable even for a pedestrian, but though so retentive of moisture it contracts to an unusual extent on drying when its surface becomes seamed with broad, deep cracks, into which the finer material falls and so brings about a mechanical and periodical change of surface. The heavy, black soils of parts of Gujerat, Berar and other regions are by reason of their hydrology and climatic conditions eminently suitable for the cultivation of the long-staple cotton, *Gossypium herbaceum*. Various millets too are extensively

grown on a great part of the black soils, while leguminous crops such as the pulses are important in maintaining the nitrogenous content necessary for fertility where minimum amounts of manure are available. On the black soils of central India and Madhya Pradesh, gram (*Cicer arietinum*) is often grown in combination with wheat.

PRINCIPAL ALLUVIAL SOIL GROUPS

The Indo-Gangetic Basin. This great soil group crosses the whole width of northern India from Sind in the west to Assam in the east; covering more than a quarter of a million square miles, it supports the bulk of the population of India and Pakistan and provides the largest share of their agricultural income. Its soils are tractable, easily cultivated and respond rapidly to irrigation and manuring. 'Broadly speaking,' writes Sir Bryce Burt, 'there are few soils in the world more suited to intensive agriculture so long as the water supply is assured.'

In so widely spread a region there are naturally many subordinate variations in the local character of the soils, yet they all possess a common origin in their derivation from materials transported and deposited relatively recently by the numerous tributaries of the Indus, Ganga and Brahmaputra river systems. They are immature soils with weak profiles undifferentiated into defined horizons. They may be little better than drift sands in some rare instances, altering to loams, silts and clays elsewhere as a result of changing atmospheric agencies such as aridity, humidity, prevailing winds, rainfall distribution and so forth; varying biological processes also play their part. Pebbly, stony and gravelly soils are rare, and in general the normal types recall the flood plain deposits of the existing rivers. Geologists divide the alluvium into an older and a newer age-group. The former is represented by the higher ground rising above the flood level of the present-day rivers and is known as *bhangar*, or 'high land', in Uttar Pradesh and Bihar. It is usually composed of massive clays or compacted silts of rather pale to reddish brown colours, interbedded with sandy layers below a certain depth and more or less permeated with nodular *kankar*. Its commoner soils are brown, argillaceous loams with a considerably larger clay factor, less sand and more moisture than the soils of the 'low land', or *khadar*, division. This, the newer, or recent alluvium, is chiefly confined to the existing river channels, except in the deltaic tracts, and it has to a great extent been derived from the older alluvium by the rivers which constantly change their courses. Its typical soils, though they vary a great deal from place to place, are pale brown sandy clays and loams which usually contain no *kankar*. While the greater part of the Gangetic plain is composed of older alluvium, the valleys of the Indus and Brahmaputra are almost wholly occupied by newer alluvium.

In the drier regions where leaching has not been excessive, though the nitrogen and humus contents of these alluvial soils are low, the proportions of potassium, phosphorus and alkalis are those of good arable soils. The oxides of iron and calcium range between wide limits, their sand grades between fine and medium, the clay factor is high and the base-exchange capacity fair. In spite of wide variations of textural characteristics, the soils are in the main azonal, that is to say devoid of the profiles displayed by more mature kinds. Although the thickness of the alluvial deposits themselves is probably to be measured in thousands of feet both in Bengal and in the Punjab, the blanket of soil covering them is rarely more than 3 to 5 inches thick, its separate horizons being indistinguishable or but very faintly marked. In the Brahmaputra valley, and the whole of the Assam plain is one great *khadar* or strath, the soils show more effects of leaching from a rainfall which continues practically throughout the whole year, and are consequently low in lime, magnesia and potash. The average lime content of a number of soils from the Brahmaputra valley was but 0.08 per cent compared with 1.0 per cent in a number of soils from the Ganga basin. The corresponding figures for potash were 0.25-0.35 and 0.65-0.70 and for magnesia 0.50 and 1.3 per cent, in the cases of the Brahmaputra and Ganga valley soils respectively. The low content of lime is supposed to be one of the reasons why three-quarters of the 820,000 acres devoted to the cultivation of tea in India lie in Assam and the adjoining districts of northern Bengal.

At the other extreme, in the drier parts of northern Bihar, Uttar Pradesh, the Punjab, Rajasthan, Sind and Madras, the interzonal groups of the alkaline and nitre-impregnated soils occur in some districts. Scanty rainfall, high temperatures and inadequate natural drainage, the result of underground obstructions such as impervious clays, combine to inhibit the normal processes of leaching, and, causing subsoil stagnation, are responsible for the barren lands (*usar*) rendered worthless for cultivation by the accumulation of saline and alkaline earths (*reh* or *kallar*). The subsoil waters of such tracts are carriers of soluble salts, particularly the chloride, sulphate and carbonates of sodium. Under arid conditions the solutions rise to the surface by capillary action, are desiccated there by solar evaporation and deposit their load of deleterious compounds in the pore spaces of the surface soil. Such occurrences are unknown in more humid regions. Unfortunately, the waterlogging of low ground by seepage from irrigation canals, particularly in the Punjab, is causing the extension of such tracts at an alarming rate. The compounds present in *reh* alter the whole composition of the surface soil, replacing the aluminium of its clay content by sodium and leaving it sterile and untillable. The nitrate-impregnated soils of parts of Bihar and the Punjab are formed by much the same series of processes but they owe their

origin entirely to human activities. They are described under POTASSIUM.

Fringing the alluvium of the Indo-Gangetic plain are the tracts known as the *bhabar* and the *tarai*: the former is simply the slope of gravel and shingle along the foot of the Outer Himalayas, in which the water of the mountain streams disappears to reissue again at the base of the slopes in the form of springs in the marshy tract of the *tarai*. The porous soils of the *bhabar* support dense forests in which the *sal* (*Shorea robusta*) flourishes, but lower down in the *tarai* there is a rich growth of high, coarse grasses. Along the edge of the Khirthar Range which fringes the western limit of the Indus plain in Sind, there is a well-marked gravel slope, comparable with the *bhabar*, seldom exceeding 1 to 2 miles in breadth, except where the rivers issue from the range itself. In Baluchistan, great slopes of gravel, known as *dhaman*, fringe the foot of the hills, and often reach a width of many miles in this comparatively rainless region. They occur as great inosculating fans spreading out from the mouths of the stream valleys and are generally devoid of a soil mantle.

The deltaic soils of the Ganga and Brahmaputra are but the natural continuations of the recent alluvial flats further upstream; of a general loamy character, they are richer in humus and they owe their inexhaustible fertility to the widespread annual flooding and the renewal of the surface soil with fresh silt which it brings about. Rice is the principal crop to which two-thirds of the whole cultivated area is devoted; oilseeds and jute are also of great importance. In the lower parts of the delta, river channels anastomose in many directions, often between banks higher than the intervening flats, and it is on these that the persistent marshes (*bhils*) with their typical soils develop. Conditions such as these doubtless give rise to the peaty layers sometimes found in the soil profiles of the lower delta, as well as to the peat beds known to occur in and around Calcutta and other places at shallow depths in the alluvium. In the upper part of the Indus delta the whole surface is composed of loose, micaceous sand with but little clay, but nearer the sea the soil becomes more argillaceous and firm.

Other Alluvial Soils. The older alluvial deposits of the Peninsula include the principal plain of the Narmada valley, extending for some 200 miles, with a breadth of 12 to 35 miles from eastwards of Jabalpur to Harda, its deep alluvial soils being very favourable to the growth of wheat. The Tapi valley has a large plain in Khandesh, extending for 130 miles and up to 30 miles wide, terminating to the eastward near Burhanpur. It is connected by a narrow alluvial belt with the plain of the Purna, one of its tributaries, and in this case the flat land stretches for about 100 miles terminating near Amraoti, while in places it is 40 miles across. In both valleys the fertile soils are derived from the stiff, reddish,

brownish or yellowish clays with the intercalated sands and gravels of which their alluvial deposits are composed. *Kankar* and pisolitic ironstone granules are frequent in them. In the eastward-flowing rivers such as the Mahanadi, Krishna, Godavari and Cauvery there are no broad and well-defined alluvial plains of this character, though they all contain narrow alluvial flats in places, sometimes of considerable extent. Brown clays with *kankar*, beds of sand, sandy silt and calcareous conglomerates are all found in them.

Along the east coast of the Peninsula from the delta of the Ganga to Cape Comorin, except for a short interruption of a few miles near Visakhapatnam, there is a belt of alluvial deposits, varying greatly in breadth, but nowhere exceeding about 50 miles. In places where the Eastern Ghats approach the sea, only a comparatively narrow sandy tract remains, but broad deltaic plains extend inland for many miles about the mouths of the rivers, particularly those of the Mahanadi, Godavari, Krishna and Cauvery. In the north, the older alluvium of Orissa joins the older alluvium of the western side of the Ganga, and there is little difference in either their constitution or their soils.

The deltas of the Godavari and Krishna unite and form the largest plain of the coast, extending over hundreds of square miles around the brackish-water Lake Colair—a hollow between them still to be filled in. Their alluvial deposits are partly of estuarine and partly of freshwater origin, the former yielding sandy surface soils and the latter dark-coloured to black 'washed up' *regur*. Southwards from these deltaic regions the coastal alluvial zone contracts greatly in width along the shores of the Nellore and Chingleput districts until those of the South Arcot and Tanjore districts, with the delta of the Cauvery, are reached, for the delta of the Penner is of small extent and appears to have been largely removed by marine erosion. The soils of this section of the coast are generally poor and often impregnated with saline substances. Between the coastal sand dunes and the higher ground further inland there are numerous lagoons and backwaters, of which the Pulicat Lake is the best example. Their dark-coloured sandy muds crumble on drying to saline black soils full of organic matter, which after cleansing by irrigation become cultivable. They are usually underlain by light-coloured mottled and sludgy clays which sometimes contain sandy and calcareous layers.

The deltaic alluvium of the Cauvery occupies wide areas in the districts of Tiruchirapalli and Tanjore and extends northwards to join the alluvium of the Vellur river in South Arcot. In the Vellur valley there is 'perhaps the largest extent of black humid soil of all the alluvial deposits of the different river systems in this part of southern India'. It was formed in an inland swamp or lake to the west and south of Vriddhachalam, and exactly resembles the soil formed in the great backwater of Marakkanam to the north of Pondicherry, as well as those under formation in the beds

of tanks in this part of the country. Dark humid soils also occur above and about the head of the Cauvery delta which when dry are not unlike true cotton soils, though somewhat less friable; when wet they are said to develop considerable plasticity without assuming a clayey character. Farther down the deltaic plain the soils are decidedly sandy, and clayey beds are very rare and of limited extent; irrigation however ensures its fertility, rice and oilseeds being the principal crops. It should be noted that the alluvium of the Cauvery extends far inland past Tiruchirapalli to beyond Karur, a distance of 120 miles due westwards from the sea, and also continues up its tributaries the Amravati and the Noyil. Cotton and tobacco thrive on this fertile riverine land 'where irrigation must be almost as ancient as agriculture itself'.

Further south still in the districts of Madurai and Tirunelveli, the coastal alluvium continues up the valleys of a number of smaller rivers, and especially so in the case of the Vaigai which feeds the plains of Madurai and Ramanathapuram. Practically the greater part of the surface of the coastal plain is 'made ground', as it has been under wet cultivation for many centuries, and such long-continued irrigation has in many cases raised the surface of the ground itself by warping. Over very large tracts of country the surface is completely hidden by paddy fields or by the waters of the very numerous irrigation tanks, many of which are of considerable extent. It is only in the smaller river valleys where the alluvium is not so disguised by cultivation that an occasional section reveals its true character, which is very similar over the whole area as nearly all the rivers rise on the gneissic rocks of, or at the foot of, the southern Ghats. The prevailing type is then found to be a pale red or reddish white or pale brownish sandy loam passing into clay or nearly pure sand in some places. The alluvium near the mouth of the Vaipar, which enters the sea north of Tuticorin, however, is exceptional, consisting as it does of dark grey or fine greyish brown silt, owing to the admixture of debris carried from an area of black soil traversed by one of its tributaries.

From the mouth of the Tambraparni almost to Cape Comorin, the coastal alluvium is largely buried under accumulations of blown sand and particularly by the red sand-hills known as *teris*. They owe their origin to the action of heavy and continuous gales during the south-west monsoon season, on the broad belt of deep red loams which skirts the eastern base of the Ghats. The surface soil is swept clean by these fierce winds, and vast clouds of red dust are carried away to the eastwards and dropped near the coast. There they become partially solidified, and percolating rain-water washes the lighter material down the slopes and into hollows where, on drying, rather hard dark red loams are again formed which are fairly fertile. They are by no means barren sand heaps but reclaimable wastes which, given sufficient water, can be used for cultivation. The various localities in the eastern coastal alluvium

where salt is manufactured by the solar evaporation of sea water are mentioned under SALT.

The west coast of the Peninsula is for the most part rocky, and alluvial deposits are confined to the vicinity of the small rivers flowing down from the Western Ghats, and to the backwaters and lagoons which are best developed in Malabar and Travancore and do not occur further north. North of Bombay and about the mouths of the Tapi and Narmada, a broad alluvial plain, resembling in some ways those of the East Coast, commences near Daman and covers the greater part of the Surat, Baroda and Ahmedabad districts. Near Surat it is about 30 miles wide, near Baroda it increases to about 60 miles in breadth. While the alluvium of eastern Gujerat consists mainly of brown clays with *kankar*, resting on sands, sandy clays and occasional gravels, covered with a blanket of black soils to the southwards, the latter do not extend into the Ahmedabad district. In north-eastern Saurashtra, on the borders of the Rann of Kutch, there is a large alluvial tract continuous with the alluvium of Ahmedabad and similar in character. The south coast of Saurashtra possesses very little alluvium, but it reappears again in Kutch where it is from 3 to 10 miles broad, and in the form of a brown loam resting on mottled clay with *kankar* and quartz grains.

AEOLIAN DEPOSITS

Between the Indus and the Aravalli Range lies what is often termed the Indian Desert, though the term is not really appropriate for the whole area of over 40,000 square miles which, though generally devoid of a soil cap of agricultural utility, is neither completely barren nor uninhabited. Shrubs and grass tufts are scattered thinly over the whole area, small trees are found in places, while villages manage to maintain their herds of camels, cattle, goats and sheep. Moreover, it has its cities with their palaces, and wells hundreds of feet deep. It is in fact a great sandy tract without any running water and a large portion of its surface consists of blown sand.

Isolated sand-hills occur throughout the whole region, but some parts of it are covered entirely by sand dunes. One tract known as the *thar* extends from the Rann of Kutch, past Umarmot, in the Thar Parkar district of Sind, where it is 60 miles or so across, to the north of Jaisalmer into Bahawalpur and Bikaner; to the east of Rohri it still maintains a width of 50 miles. There is another great tract of sand dunes further to the eastwards, which starting again from the Rann of Kutch extends north-eastwards to the west of the Luni river between Balmer and Jodhpur, and coalesces with the first tract in Bikaner; between Jodhpur and Pokaran this belt of dunes is about 40 miles across.

The accumulation of the sand is due to the low rainfall, usually less than 6 inches annually, and the consequent absence of streams.

In those parts of Rajasthan with a heavier rainfall, or again to the northward in the Ganga valley, the sand-hills disappear. There are occasional sand-hills in the Indus valley in Sind and there are tracts in the Western Punjab where the phenomena of the *thar* and the Rajasthan 'desert' are repeated on a diminutive scale. Such tracts include the Sind Sagar Doab between the Indus and the Jhelum, a barren tract in the Rachna Doab between the Chenab and the Ravi, and the sand-hills of the Bari Doab between the Ravi and the Sutlej.

Dunes of wind-borne drifted sand occur in parts of the coastal tracts of Orissa and the Ramanathapuram, Tirunelveli and Malabar districts of Madras as well as about Surat, Broach, parts of Saurashtra and the Kutch coasts of western India. They are also to be seen on the banks of rivers in the peninsular and extra-peninsular regions, and they account for the *bhur* lands of northern India and Pakistan, the literal meaning of the word *bhur* being 'sandy soil'.

Of related origin are the fine-grained, unstratified dust deposits of some arid regions, where the strong winds of the hot weather, sweeping over a parched and friable soil, strip the rocky elevations of all but a thin layer, retained by a scanty growth of grass, and deposit the soil in more sheltered places or on the open plains where it settles and accumulates. According to R. D. Oldham, enormous areas in the Son valley are covered with such material, which when wet passes into a slimy and impalpable mud and when dry indurates to the consistency of rock. C. S. Middlemiss thought that much of the sandy alluvium of the river valleys of Idar, Bombay, was probably more of the nature of wind-borne loess than the result of the action of running water. But it is in the Punjab and in areas of enclosed drainage in Baluchistan where loess deposits reach their greatest development. Dr D. N. Wadia has described how the surface of the sub-Recent deposits of the Potwar, especially towards the north, are covered with an unconsolidated, unstratified, structureless, wind-borne drift, spreading alike across depressions, slopes and higher ground, which though soft and easily denuded can still stand in high vertical walls. The weathering of this uncompacted, calcareous and partly saliferous dust into 'a deep labyrinthine fretwork of defiles and chasms has produced the characteristic "bad-lands" topography of parts of the Potwar, locally designated as *khuddera*', and in it perpendicular-sided ravines of 300 feet depth are not uncommon. The loess deposits of Baluchistan are described as fine-grained, usually grey coloured and unstratified accumulations of wind-blown dust, precisely similar to the great loess deposits of China. They vary in size from patches of a few yards across to great plains like that of Thal-Chotiali. In the Kachhi, as the plain south of Sibi is called, the wind-blown loess is more or less mixed with true alluvium.

MOUNTAIN SOILS OF EXTRA-PENINSULAR REGIONS

The outer margin of the Himalayas is formed by a continuous fringe of foot-hills built of the rocks of the Siwalik Series, the outermost stage of which consists of thousands of feet of loosely aggregated conglomerates with soft sandy beds immediately below them. As a general rule they are sharply marked off from the *bhabar* deposits already mentioned, though sometimes there is no distinct division between them. Such materials in a climate with a heavy monsoon rainfall give rise to shallow, immature, sandy soils of a light character with but little humus, on which the *sal* (*Shorea robusta*) flourishes up to about 3,000 feet. The hardly reclaimed, low banks of the rivers and their islands support the *sissoo* (*Dalbergia sissoo*) and the *khair* (*Acacia catechu*), while on the drier and more stony low ground and in the hollows at the base of the hills the bamboo (*Dendrocalamus strictus*) is common. In the foot-hills of Kumaun and Garhwal, banks of coarse gravel and torrent boulders, generally mixed with ferruginous sand and clay, line the margins of the rivers and larger streams besides covering great portions of the *duns* and *chaors*: local terms applied in the first-named to the valleys, and in the second to the level or slightly sloping ground generally elevated above the neighbouring drainage lines. In places where the streams carry much lime in solution, beds of calcareous tufa are interstratified with the gravel banks and sandy clays. Although it is convenient to denote the three stages of the Siwalik Series broadly as the Conglomerate, Sandrock and Sandstone Stages, it must not be supposed that each of these rocks constitutes the whole of each formation. The conglomerates sometimes contain sandy, loamy and clay beds amongst their alternations of coarse and fine bands. The Middle Siwalik sand-rock contains conglomerates near its base, yet the formation as a whole is so soft that, wherever it is exposed, the whole countryside is in a state of rapid disintegration and in extreme cases forest trees are unable to obtain sufficient root-hold to thrive. The lowest, or Nahan Stage differs from the sandrock mainly in its greater degree of induration; it too possesses beds of loam and clay usually of red and purple tints. These minor lithological differences, however, do not appear to cause much variation in the character of the Siwalik soils as a whole, or of the forests with their rich undergrowth of shrubs, coarse grasses and herbaceous plants which grow upon them. 'The particular petrological constitution of any part of the Sub-Himalaya,' wrote G. S. Middlemiss, 'varying but slightly in its chemical elements and state of solidity from its neighbouring zones of Tertiary age, does not seem to be a very important factor in determining the nature of the forest stock. The several rock stages of the Sub-Himalayan formations being very much alike in their general facies and in the ultimate material into which they can be reduced, produce, of necessity, a very similar soil under like conditions of drainage and aspect.'

The northern limit of the Tertiary zone is the main boundary fault, one of the most constant features of Himalayan tectonic geology: it is also the limit of the *sal* tree and therefore of the reserved forests in which it is conserved. If they extend beyond it at all, they never pass beyond the zones of rocks of Nummulitic and Mesozoic age which intervene before the ancient rocks of the higher ranges are reached. Thus the change after crossing the boundary fault is a most marked one; the undulating *duns* and *chaors* of the younger formations disappear; 'with the change in the nature of the rock,' to quote Middlemiss again, 'there follows a change in that of the soil, and in the vegetable products of the soil. The jungles lose their depth and vastness, and their tropical characteristics seem to give way with magical abruptness. The country is much barer to the north. The hillsides become covered with small villages, each with its little plot of terraced fields and straggling uncared-for jungle round about.'

Important though geological causes have been in influencing such changes, their role is subordinate to that of increasing altitude and the concomitant development of a temperate climate in the zone ranging say from 5,000 or 6,000 feet to 11,000 feet or so. The place of the *sal* forests of the Sub-Himalaya is now taken by pine forests, though many other conifers occur in this zone as well as magnolias, oaks, laurels, birches and rhododendrons. Shrubby varieties of the last-named, as well as a few birches and junipers, even cross the normal edge of the tree line into the still higher alpine zone. The limit of forest vegetation is from 12,000 to 14,000 feet, above which the soils are frozen for the greater part of the year. Systematic surveys of Himalayan soils have still to be undertaken, and at present very little is known of their genetic relationships, composition and physical properties. When the results of such investigations are available they will undoubtedly reveal a great diversity of soils of many characters, varying from the rich and highly fertile kinds in such broad lateral valleys as those of Kashmir and Nepal, or, again, the soils devoted to the cultivation of tea in Kangra or Darjeeling, to those of the higher Himalaya on which a very specialized flora struggles to maintain an existence; from those of mountain-forest and mountain-meadow types to those of the bleak highland steppes. It is believed that podsolized soils have been developed on a large scale under the higher coniferous forests, for they are known to possess the characteristic greyish white colours due to excessive leaching of the upper layers. Wadia, Krishnan and Mukerjee have stated that in the Middle Himalayas the soils are generally scanty, that the southern slopes of the mountains usually consist of naked rock, bare of any kind of regolith, and that glacial, fluvio-glacial, talus and rain-wash soils, often intermingled by the action of surface creep, may clothe the northern slopes and support grass lands and meadows which can be turned to agricultural uses on a small scale, at elevations of over

7,000 feet. The valleys of this zone are choked with drift gravels and smaller debris, often the resorted remains of morainic material from above the snow line, and on terraces where any finer alluvium has accumulated the scanty population usually manages to create small spreads of cultivable land.

The soils of parts of the Chittagong Hill Tracts of East Pakistan and their continuations further north, a forested region with a copious rainfall and good natural drainage, have developed characters of their own, described by P. K. Ghosh as 'lateritic-cum-podsolic', an earlier stage of lateritic weathering having been replaced by a process somewhat akin to podsolization. In the profiles of such soils, the upper layer, or 'A' horizon, is loamy, while below in the 'B' horizon there have been losses of some 15 per cent of silica and gains of nearly 13 per cent in the sesquioxides of iron and aluminium and of about 1.5 per cent in the lime content.

In the preparation of this note on soils, we have drawn freely on the writings of Dr D. N. Wadia, to whom we wish to acknowledge our indebtedness.

Modern studies of Indian soils date from about 1928 and are in large measure the work of the Soils Branch of the Imperial Council of Agricultural Research and the Agricultural Departments of the separate States. The Indian Society of Soil Science, founded in 1935, has done much to advance the genetic studies of soils on up-to-date lines. A Soil Map of India was published in 1943, prepared by B. Viswanath and A. C. Ukil of the Departments of Soil Science and Agricultural Chemistry in the Agricultural Research Institute. In 1942 work had already commenced on the All-India Soil Survey Scheme sponsored by the Indian Council of Agricultural Research. It resulted in the publication of a report in 1953 together with soil maps of India and of the States based on existing data. It contains a particularly important section dealing with the soils of the various regions in relation to the crops produced upon them. Under the Indo-American Technical Co-operation Programme, six zones were set up at Poona, Delhi, Kanpur, Coimbatore, Nagpur and Sabour to study data on the fertility of the original soil and its improvement by the use of fertilizers. Statistical studies are now being made at the Indian Council of Agricultural Research and the Indian Agricultural Research Institute. A laboratory for research in agriculture with radioactive isotopes has been provided for and a building for the laboratory is under construction. Much of the equipment for the laboratory has arrived and an American technician is assisting in the research. In May 1954, a supplement to this project was signed in New Delhi providing for the installation of sixteen soil-testing laboratories in different parts of India as well as for expansion of existing soil survey zones, setting up of soil physics laboratories at two existing State soil laboratories and a mobile soil testing

laboratory. The United States commitment for this project totalled \$329,850 and the Indian Rs 24,62,540 up to the end of June 1954. Another noteworthy advance is the provision of Rs 2 crores by the Central Government towards the cost of works undertaken by the States for the control of erosion in hilly districts and for soil conservation generally. Much still remains to be done, however, particularly in the way of large-scale soil surveys and mapping, not only to trace the distribution and relationships of particular groups but to comprehend the processes of their formation and to arrange their orderly classification. Such knowledge is of primary importance in all investigations concerned with the fertility of the soil or with the betterment of agricultural and forestal practice. In the furtherance of these branches of pedological science the co-operation of the geologist can be of great assistance to the agricultural specialist, but the geologist is equally concerned with those aspects of the subject usually grouped together under the term 'soil mechanics', for the soil itself cannot be dissociated from many problems of ground-water supply and civil engineering. The latter include the construction of dams and reservoirs; roads, railways and bridges; the stability of road and railway cuttings, particularly in hilly districts; the foundations of high buildings; the lay-out of new towns; the sites of airfields; the alignments of canals, and questions relating to soil erosion and to soil contamination by both natural and artificial agencies.

THE PRINCIPAL SOIL GROUPS OF BURMA

The delta of the Irrawaddy consists mainly of a yellowish brown to reddish clay recalling that of the Gangetic plain but with much less calcareous matter and a higher proportion of sand. Its lowest beds as revealed by tube-wells in Rangoon and elsewhere are clean yellow and buff sand and pebble beds of rounded quartz. In places on the surface of the deltaic clays there are deposits of sand and silt resembling the *khadar* of the Ganga valley. The deposits of the Sittang delta are of much the same nature.

Outside the delta of the Irrawaddy there is no continuous alluvial plain in any way comparable to those of the valleys of the Ganga, Brahmaputra or Indus; spreads of alluvium of varying width do occur in places along the banks of the river and its tributaries, but the soils of the valleys above them, both in Central and in parts of Upper Burma, are derived either from the local rocks of the Irrawaddian System or from the extensive terraces of the ancestral river, of which at least five are known to exist at various elevations in the Dry Zone. According to de Terra, these terraces display four major soil formations as follows: Red Earths associated with Terrace No. 2; Lateritic Gravels, corresponding to Sir Edwin Pascoe's 'Plateau Red Earth' of Pleistocene age, of the uppermost Terrace and of still higher surfaces; a fine-grained

pluvial product reworked by wind action and containing much carbonate of lime, not unlike the Potwar Loess of Western Pakistan in appearance, found on Terraces Nos. 3 and 4; and a silt on the surface of Terrace No. 5, nearly related to the recent silt of the great river. Between the river terraces and the ridges of the Pegu Yoma in the Dry Zone, there are hilly uplands blanketed with a thin veneer of lateritic soil and probably forming the primary land surface. On the higher slopes of the Pegu Yoma red silts of aeolian origin are frequently met with.

The Irrawaddian rocks themselves yield thin, poor, sandy soils, varying between almost pure sands and sandy loams; they are often ferruginous and gravelly and tend to form pan soils. Alternating beds of sandstone and shale yield loams passing into stiff clays where shales become the predominant member. Dr H. L. Chhibber has described certain black earths from the Dry Zone and elsewhere, always occurring at low elevations in conditions of restricted drainage, as closely resembling the Black Cotton Soils of India. Sticky and tenacious when wet, they crack deeply on drying and contain calcium carbonate throughout the whole profile with its concretions in the subsoil. In the more arid parts of the Dry Zone, yellow and brown, saline and alkaline soils are common.

Between the Dry Zone of the Central Basin and the forested highlands leading to the Shan Plateau, there is a belt of country with an intermediate rainfall, characterized by soils with hard pans and high lime contents. The great expanses of the Plateau Limestone of the Shan States are mantled by thick deposits of red clay (*terra rossa*) of a residual nature, yielding somewhat sterile soils which frequently contain ironstone concretions and are devoid of lime. Some of the older Palaeozoic rocks of the Shan States yield sandier soils as also do the Jurassic sandstones of the Nam Yau System. There are many intermontane basins with thick deposits of sands, clays and silts of fluvio-lacustrine origin.

Little is known of the soils of the Northern Hills and Frontier Regions beyond the fact that red earths and loams are common in them, with transported alluvial soils in valley locations where deposition has been possible. The evergreen temperate forests of these regions are usually associated with a reddish loamy type of soil, commonly 5 to 7 feet thick, but of much greater depth at the bottom of slopes. Of the soils of the Arakan Yoma even less is known though they too have been generally classified as red loams; their foot-hills are often covered with gravel and sand deposits of considerable thickness.

Lateritic soils are commonest in the coastal districts of Tenasserim. Detrital laterites are also found on the edges of the alluvial tracts of the Irrawaddy and Sittang, as well as along the western foot of the Pegu Yoma. They also occur in some parts of Upper Burma, where suitable climatic conditions and rocky foundations

exist for their formation. The lateritic soils of the Dry Zone were formed when its climate was more humid than it is today.

The typical soil of the Mergui Series, which covers much of Lower Tenasserim, is a brownish or reddish clay graduating downwards into compact, mottled lithomarge. The soils of the granitic intrusions contain a higher proportion of sand, are rich in humus and support high, tropical evergreen forests.

For fuller information than it is possible to give here reference should be made to Chapter XIV of Dr H. L. Chhibber's *Mineral Resources of Burma*. This chapter, written in collaboration with S. P. Aiyar of the Burma Agricultural Service, summarizes the knowledge possessed up to 1934. Later results dealing with certain special areas appear in Hellmut de Terra's *Pleistocene of Burma*.

APPENDIX

INDIA'S MINERAL PRODUCTION IN 1951, 1952 & 1953 Output in tons unless otherwise stated.

		1951		1952		1953	
		QUANTITY	VALUE Rs	QUANTITY	VALUE Rs	QUANTITY	VALUE Rs
FUEL							
Coal	54,432,396	..	50,48,11,354	36,303,589	53,62,35,440
						35,979,167	52,76,26,928
METALS AND ORES							
Aluminium	3,849	(a)	1,15,47,000	3,566	(a) 1,05,19,700
Bauxite	67,047		7,52,365	63,505	7,67,241
Chromite	16,702		9,13,087	35,187	18,36,753
Copper	7,083		2,27,78,998	6,079	1,95,50,854
Copper Ore	969,057		1,94,00,550	324,635	1,63,45,504
Gold	226,364	(b)	6,75,30,706	253,264	6,04,31,773
Ilmenite	224,084		40,24,700	224,895	37,30,123
Rutile	45		8,820	147	69,001
Iron Ore	3,657,105		2,09,52,916	3,925,511	2,68,33,315
Iron (Pig)	1,802,037	(c)	5,20,90,168	1,810,178	(c) 4,18,88,192
Steel	1,069,749		33,59,01,186	1,117,552	45,14,91,008
Ferro-Manganese	23,414		1,24,06,050	11,455	63,00,250
Ferro-silicon	2,915		15,00,000	3,728	17,38,000
Lead	859		17,83,47,750	1,132	(d) 22,44,57,524
Manganese Ore	1,292,375		70,310	1,462,264	73,557
Silver	14,612	(b)	17,675	(b) 17,675	
						1,897,698	(d) 29,41,43,190
						(b) 16,364	64,418

1 crore = 10,000,000.

1 lakh = 100,000. Exchange @ 12. 6d. sterling or 21 U.S. cents to the rupee.

(a) Estimated. (b) Oz. (c) Value of pig-iron left after the steel industry's consumption. (d) Estimated on export value.

INDIA'S MINERAL PRODUCTION IN 1951, 1952 & 1953—Continued

	1951		1952		1953	
	QUANTITY	VALUE Rs	QUANTITY	VALUE Rs	QUANTITY	VALUE Rs
Tin Ore .. ..	....	....	7	2,086	0.2	892
Wolfram concentrate ..	(a) 14.25	1,49,625	(a) 10	1,50,000	(a) 15	1,80,000
Zinc concentrate ..	2,110	(b) 5,73,920	3,867	(b) 10,31,824	4,302.5	(b) 11,70,280
GEMS AND SEMI-PRECIOUS STONES						
Aquamarine .. ..	....	....	(c) 600	4,150	....	....
Diamond	(a) 1,674	5,34,361	(c) 2,054	4,78,299	(c) 2,207	5,61,620
Emerald	(c) 252.995	2,56,948	(c) 461,872	2,77,740	(c) 550,938	2,30,374
OTHER MINERALS						
Apatite	416	6,408	445	6,940	4,359	42,052
Asbestos	518	2,36,762	865	4,93,429	568	5,47,883
Barytes	10,471	3,10,957	10,030	3,06,670	4,057	71,449
Bentonite	164	3,725	370	15,000	292	3,255
Calcite	1,380	24,550	3,582	42,903	2,299	32,216
China clay	69,096	18,56,324	85,963	18,64,852	109,370	19,58,674
Clays, other than china clay or fireclay.	182,596	4,05,736	332,690	5,64,707	....	....

(a) 65% WO₃
 (b) f.o.b. Bombay value.
 (c) Carats.

	1951		1952		1953	
	QUANTITY	VALUE Rs.	QUANTITY	VALUE Rs.	QUANTITY	VALUE Rs.
Corundum ..	554	2,28,547	637	2,56,775	273	85,973
Feldspar ..	3,385	36,932	2,020	29,863	3,746	39,567
Fireclay ..	112,563	8,00,014	118,999	9,35,630	71,979	5,53,629
Fuller's Earth ..	4,000	69,000	8,132	2,23,381	1,722	71,667
Graphite ..	1,735	2,31,657	2,881	3,13,498	767	69,092
Gypsum ..	203,612	12,63,128	411,304	31,02,351	582,713	38,14,338
Kyanite ..	42,501	58,56,626	26,882	63,16,876	15,034	23,49,004
Limestone ..	5,199,906	4,18,72,117	4,923,715	2,25,98,373	....	....
Magnesite ..	117,466	18,59,934	89,041	16,18,107	92,748	18,24,889
Marble ..	21,373	6,33,792	17,587	4,97,283	....	....
Mica* ..	(a) 490,665	15,75,11,134	(a) 807,402	9,58,23,410	(a) 245,400	8,47,53,264
Ochre ..	11,292	1,34,050	17,600	3,04,929	15,173	1,79,353
Pyrites ..	530	26,500	2,168	1,06,232	277	15,512
Salt ..	(b) 2,642,043	6,05,20,367	(c) 2,678,253	5,25,77,079	(d) 2,972,059	5,47,32,000
Saltpetre ..	5,212	(e) 35,84,084	8,384	49,91,000	(f) 2,777	15,02,880
Sillimanite ..	4,048	1,97,577	5,076	3,76,489	4,941	4,20,824
Slate ..	15,401	6,08,686	16,878	6,51,160	....	....
Steatite ..	33,647	13,39,268	20,772	7,64,224	28,571	16,43,041
Vermiculite ..	232	6,352	22	550	....	....

* Export figures.

(a) Cwt.

(b) Excluding 91,897 tons produced without licence.

(c) " 147,904 " " "

(d) " 192,978 " " "

(e) Excluding the value of 39 tons.

(f) Incomplete.

A SHORT LIST OF SELECTED PAPERS

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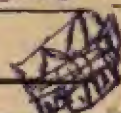
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